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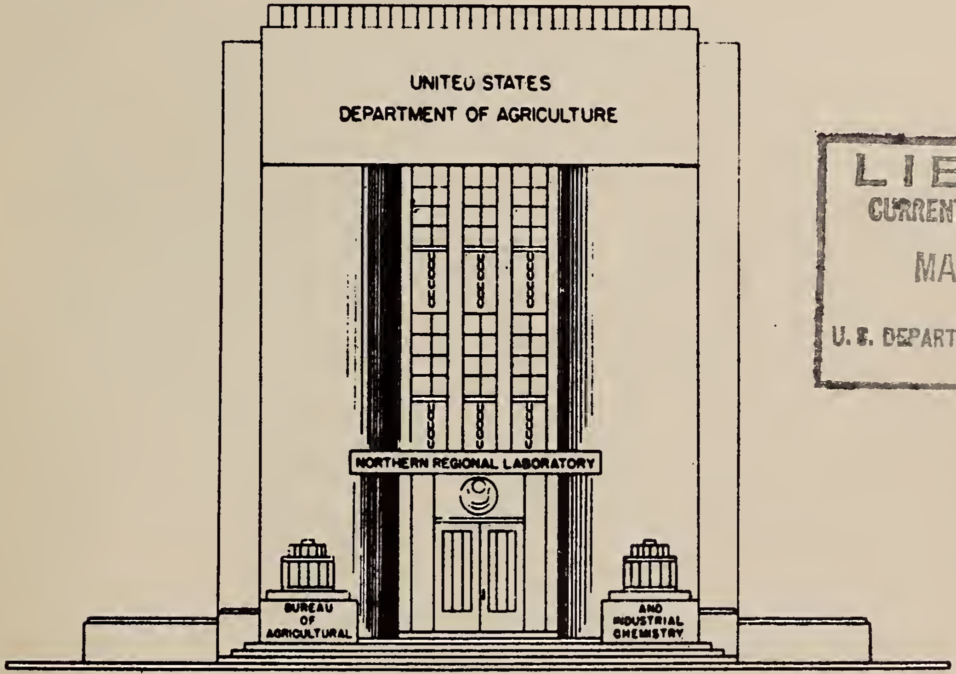
CORNCOBS--THEIR COMPOSITION, AVAILABILITY, FARM AND INDUSTRIAL USES



By

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By E. C. Lathrop[1] and J. H. Shollenberger[2]

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INTRODUCTION

The Northern Regional Research Laboratory, Peoria, Ill., is one of four large research laboratories established, under authority of the Agricultural Adjustment Act of 1938, by the U. S. Department of Agriculture and placed under the administration of the Bureau of Agricultural and Industrial Chemistry of the Agricultural Research Administration.

The functions of these laboratories are to conduct researches into and to develop new scientific, chemical, and technical uses of, and new and extended markets and outlets for, farm commodities and the products and byproducts thereof. The commodities being worked on in the Northern Regional Research Laboratory are wheat, corn and other cereal crops; soybeans and other oilseed crops, excepting cottonseed and peanuts; and agricultural residues.

Agricultural residues include corncobs, straws, stalks, stems, hulls, bagasse, etc. It is estimated that 200 million tons of these residues are produced annually, of which about 20 million tons are cobs. The quantity actually available for processing, however, is much less. It is this quantity and its cost to industry that make up the primary considerations in the industrial utilization of this material.

The quantity of residues available is dependent upon concentration of production, farm practices, and uses made of them on the farm. The cost of these residues to industry is made up chiefly of collection and transportation costs, which in many instances in the past have been higher than industry could bear. During World War II, when price was of secondary consideration, possibilities for utilization were increased. Since from these residues it is possible to make a wide variety of products essential not only to war economy but to normal economy, this vast reservoir of annually replaceable raw materials is assuming increasing importance as a national resource. Indeed, the depletion of resources during the war and the changes under way in our postwar economy are directing the attention of industry more and more to these raw materials.

The problem of agricultural residue utilization is not new. Thousands of scientific papers, patents, and descriptions of processes for the industrial utilization of one or another of these residues is found in the literature. On the other hand, successful industrial utilization of any permanent character, in the light of the effort expended, has been very small. Too frequently the attempted utilization of these residues has been based on the false assumption that these agricultural materials cost practically nothing, and that low-cost

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substitutes might be made from them. Then, too, the importance of ability to merchandise products manufactured from them and the bearing of sound business management on the success of the venture has not been recognized in many cases.

From a study of the successes and failures in this and other waste utilization fields several rather simple guiding principles for research on residue utilization have been developed by this Laboratory. Such success as the few subsequent years have brought to this work are due to adherence to these principles, which stated briefly, are as follows:

1. Establish procurement of the residue material on a sound economic basis. This involves collection, packaging, transportation, storage and preservation of such material, and sound contractural relationships with suppliers.

2. From a thorough study of the physical and chemical properties of a residue material determine wherein it may render services in industrial usage not so readily supplied by other raw materials. Establish uses based on its superior or unique properties.

3. In the development of processes to utilize a residue, eliminate waste products to the greatest possible extent. Attempt to obtain the maximum utilization by producing major co-products instead of by-products or wastes.

4. Recognize that markets must be explored, merchandising plans perfected, and proper financing arranged before investment in plant facilities is made. Sound business management and sound merchandising of the product will prove as important to success as a sound conversion process, operated on an economical competitive basis.

This report contains information concerning the physical and chemical properties of cobs, their availability, their present farm and industrial uses, and some indications of future possibilities of utilization. From about 1937 to 1947 the industrial utilization of cobs increased from about 10,000 tons to 200,000 tons per year. During the war years about 40 to 50 plants processed cobs for various purposes.

COMPOSITION

Structural Composition and Physical Characteristics

There are two colors of cobs, white and red. Usually yellow-kerneled corn varieties have red, and white-kerneled corn varieties white cobs. Two exceptions known are the white corn variety, St. Charles, which has red, and the yellow corn variety, Day, which has white cobs.

In shape, corncobs range from nearly cylindrical to almost conical; in length, from 1 inch for some South American pop varieties to 20 inches for some large flint and dent varieties. Generally, cobs from dent varieties are 7 to 10 inches in length, 1 to 1 3/8 inches in diameter at the butt, and a trifle smaller in diameter at the middle, tapering to about 3/4 inch near the tip.

Cobs from flint varieties are usually longer than those from dent varieties, but are considerably smaller in diameter and less tapering. White cobs, whether from dent or flint varieties, are often slightly larger in diameter than red ones.

The surface of the cob is indented or pitted where the corn kernels are attached to the cob. These pits or indentations are lined with inner and outer glumes, a large proportion of which may be removed readily from the cob by rubbing it.

Structurally, the cob may be divided into four parts: (a) Fine chaff, or beeswing (inner glumes and thin upper section of outer glumes); (b) coarse chaff (lower portion of outer glumes, the kernel caps, and the small stems on which the kernels are borne); (c) woody ring at base of glumes; and (d) pith.

The inner glume is of tissue thinness, and may be either white or red. This material is extremely light and when loosened from the other portions of the cob can be readily separated by fanning or aspirating.

The outer glume, constituting the major part of the coarse chaff, is a white or cream-colored tough, woody-like substance similar to the hard woody layer of material at its base.

The woody ring portion of the cob, here designated as part three, consists of a ring or layer of woody material at right angles to the long axis of the cob about 1/8 to 3/16 inch in thickness situated between the pith and the glumes. Its color varies from white to a pinkish-white. This is true of both white and red cobs. This portion is extremely hard and tough and relatively resistant both to abrasion and granulation. Close examination, however, reveals that this woody ring is not continuous, but is composed of woody sections containing vascular bundles. These woody sections occur in double rows staggered and interlapped in a manner resembling Zippers. Cleavage of this woody material can be accomplished with comparative ease between these double rows.

The pith is very soft, spongy, extremely light in weight, and white in color, occupying the heart or inner section of the cob and constituting about one-ninth of its volume. There are no vascular bundles in it, consequently it is granular in structure rather than stringy; the granules, however, are cemented together.

In table 1 data are presented showing the proportions by weight in which the structural components--fine chaff, coarse chaff, woody ring, and pith of an average cob--are present.

Table 1.-Weight and proportions of cob fractions (air-dry basis, approximately 12 percent moisture)

Item	Weight	Proportion of cob
	Grams	Percent
Cob, whole	46.3	100.0
Cob, fractions:		
Woody ring	27.9	60.3
Coarse chaff	15.6	33.7
Fine chaff	1.9	4.1
Pith	.9	1.9

Analysis by Commodity Development Division, Northern Regional Research Laboratory, on one cob, about normal size, of Illinois 972 hybrid corn. Length of cob, 8.4 inches; diameter at mid-section, 1.19 inches; at butt, 1.15 inches. The separations were made by hand.

Sweeney (1)[3/], grouping all chaff into one classification, gives the structural composition of cobs as: Chaff, 25.0 percent; woody substances, 73.4 percent; and pith, 1.6 percent.

Wiley (2), in separating the pith from the outer portion of the cob, reports the following proportions by weight: Pith, 1.5 percent, and shell, 98.5 percent. In determining the absorptive properties of pith, Wiley found that 1 gram of air-dry pith absorbs approximately 10.43 grams of water.

Data presented in table 2 show the percentage of pith in cobs of specified corn varieties grown in various locations, as determined by the Northern Regional Research Laboratory.

In table 3 analytical data are presented showing minimum, maximum, and average cob weights and dimensions of certain corn varieties. Comparison of maximums and minimums shows the following ranges: Weight of cob, 0.22 to 3.05 ounces; length of cob, 3.5 to 12.0 inches; diameter of cob at mid-section, 0.79 to 1.33 inches; and diameter of cob at butt end, 0.66 to 1.51 inches.

[3/] Numbers in parentheses refer to literature cited, pages 38, 39, and 40.

Table 2.-Average weights of cob and pith and percentage of pith in cobs of specified varieties

Sample No.	Variety	Where grown	Crop year	No. cobs exam.	Average Cob weight	Average Pith in cob Weight	Average Pith in cob Proportion
					Grams	Grams	Percent
	Hybrid varieties						
105	U.S. 13	Lafayette, Ind.	1940	5	39.12	.622	1.59
443	U.S. 13	Wooster, Ohio	1940	5	43.75	1.002	2.29
638	U.S. 13	Ames, Iowa	1940	25	29.48	.398	1.35
1196	U.S. 13	Lincoln, Nebr.	1940	5	49.90	.709	1.42
1523	U.S. 13	Havana, Ill.	1941	5	45.93	.735	1.60
442	U.S. 44	Wooster, Ohio	1940	25	41.11	.682	1.66
470	U.S. 44	Ames, Iowa	1940	25	29.77	.396	1.33
1197	U.S. 44	Lincoln, Nebr.	1940	5	22.40	.426	1.90
1522	U.S. 44	Havana, Ill.	1941	5	37.99	.623	1.64
439	Iowa 939	Wooster, Ohio	1940	5	37.42	.737	1.97
634	Iowa 939	Ames, Iowa	1940	25	22.96	.425	1.85
1187	Iowa 939	Lincoln, Nebr.	1940	5	22.68	.481	2.12
1226	Ill. 972	Wyoming, Ill.	1940	25	36.29	.482	1.33
	Open-pollinated varieties						
1183	Brady white	Lincoln, Nebr.	1940	5	37.42	.793	2.12
1526	Suttons white	Havana, Ill.	1941	5	61.81	.964	1.56

Analysis by Commodity Development Division, Northern Regional Research Laboratory.

Table 3.-Weights and dimensions of cobs of several dent corn varieties, based on analyses[1] of 25 cobs, selected at random, from each sample

Sample No.	Variety	Where grown	Crop	Weight of cobs			Length of cobs			Diameter of cobs at					
										Mid-section			Butt end		
				Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
					Ounces			Inches			Inches			Inches	
	Hybrid varieties														
105	U.S. 13	Lafayette, Ind.	1940	0.81	1.81	1.27	6.2	9.1	7.7	.94	1.23	1.07	1.01	1.27	1.13
443	U.S. 13	Wooster, Ohio	1940	1.16	2.25	1.61	7.4	9.5	8.4	1.05	1.32	1.16	1.13	1.45	1.29
638	U.S. 13	Ames, Iowa	1940	.58	1.55	1.04	6.4	10.0	8.0	.85	1.21	1.02	.92	1.22	1.08
1196	U.S. 13	Lincoln, Nebr.	1940	.89	2.16	1.46	6.1	10.0	8.5	.92	1.33	1.06	.94	1.28	1.11
1523	U.S. 13	Havana, Ill.	1941	.75	1.70	1.39	5.4	9.0	7.8	.94	1.15	1.04	1.04	1.31	1.14
442	U.S. 44	Wooster, Ohio	1940	.22	2.82	1.34	3.5	9.9	8.2	.85	1.25	1.06	.66	1.41	1.16
470	U.S. 44	Ames, Iowa	1940	.78	1.74	1.05	6.4	9.4	7.9	.99	1.26	1.13	.87	1.15	1.00
1197	U.S. 44	Lincoln, Nebr.	1940	.35	1.53	.99	6.1	9.8	7.7	.79	1.07	.94	.84	1.24	1.04
1522	U.S. 44	Havana, Ill.	1941	.75	1.77	1.31	6.1	9.7	8.5	.93	1.16	1.07	1.05	1.39	1.20
439	Iowa 939	Wooster, Ohio	1940	.50	2.21	1.29	4.5	9.5	7.6	.91	1.24	1.06	.83	1.36	1.15
634	Iowa 939	Ames, Iowa	1940	.52	1.49	.98	5.0	9.4	7.8	.81	1.07	.96	.83	1.23	1.03
1187	Iowa 939	Lincoln, Nebr.	1940	.61	1.77	1.07	6.4	9.1	7.8	.80	1.10	.94	.88	1.21	1.05
1226	Ill. 972	Wyoming, Ill.	1940	.87	1.78	1.28	6.9	12.0	8.3	.82	1.13	.98	.95	1.27	1.11
	Open-pollinated varieties														
1183	Brady white	Lincoln, Nebr.	1940	.72	2.11	1.26	4.4	8.5	7.1	.93	1.30	1.09	1.02	1.44	1.22
1526	Suttons white	Havana, Ill.	1941	.66	3.05	1.66	4.1	10.4	7.6	.96	1.26	1.11	1.15	1.51	1.29
Summary of all varieties				.22	3.05	1.27	3.5	12.0	7.9	.79	1.33	1.05	.66	1.51	1.13

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[1] These analyses are not on the same cobs as those given in table 2.

Analyses by Commodity Development Division, Northern Regional Research Laboratory.

Chemical Composition

Chemical analysis of corncobs, their component parts, and fractions thereof are available from a number of sources. Of these only a few of the most representative are presented here.

Average elementary chemical analysis (moisture-free basis) of two samples of corncobs by the Northern Regional Research Laboratory showed the following composition:

	Percent
Carbon	48.4
Hydrogen	5.6
Nitrogen	.3
Ash	1.4
Oxygen (calculated by difference)	45.3
Total	100.0

Morrison (3) reports the fertilizer constituents contained in corncobs as 0.37 percent nitrogen, 0.02 percent phosphorus, and 0.37 percent potassium, on a 9.6 percent moisture basis.

In table 4 is shown the chemical composition of corncobs (moisture-free basis) as reported by Morrison (3), Wiley (2), and Winton (4). According to these data, protein constitutes approximately 2.6 percent; fat, 0.5 percent; fiber, 34.3 percent; ash, 1.7 percent; and nitrogen-free extract, 60.9 percent of the dry matter of the cob.

Table 4.-Chemical composition of corncobs (moisture-free basis) as reported by three authorities

Constituent	Analysis by		
	Wiley[1/]	Morrison[2/]	Winton[3/]
	Percent	Percent	Percent
Protein	2.7	2.5	2.7
Fat	.5	.4	.6
Fiber	33.7	35.4	33.7
Ash	1.6	1.8	1.6
Nitrogen-free extract	61.5	59.9	61.4
Total	100.0	100.0	100.0

[1/] Wiley, page 28 (2).

[2/] Morrison, table 1, (3).

[3/] Winton, page 73 (4).

Wiley (2) determined the chemical composition of the pith and the shell (the cob excluding the pith). His analyses are shown in table 5.

Table 5.-Chemical composition of the pith and shell of the corncob (moisture-free basis)

Constituents	Pith	Shell
	Percent	Percent
Ether extract, or fat..	.6	.3
Fiber..................	37.2	35.4
Ash....................	2.6	1.7
Protein................	2.2	1.9
Nitrogen-free extract[1]	57.4	60.7
Total..................	100.0	100.0

[1] Difference between the determined constituents and 100 percent, not recorded by Wiley.

Chemical analysis of the structural parts of the cob--pith, coarse chaff, fine chaff, and woody ring--hand separated, are shown in table 6.

Table 6.-Analytical data pertaining to the structural parts of the cob--fine chaff, coarse chaff, woody ring, and pith (moisture-free basis)

Determination	Structural part			
	Fine chaff	Coarse chaff	Woody chaff	Pith
	Percent	Percent	Percent	Percent
Ash..................................	1.39	1.26	1.16	1.46
Soluble in 1% NaOH..................	52.3	42.0	48.0	46.2
Soluble in hot water................	7.8	7.2	9.5	10.7
Soluble in ether....................	1.3	.8	.9	1.9
Soluble in alcohol-benzene, 7 hours..	3.3	6.1	9.0	9.3
Soluble in alcohol-benzene, 20 hours.	4.4	7.0	9.5	9.4
Pentosans............................	34.2	37.4	39.2	34.5
Furfural.............................	20.0	21.8	23.0	20.1
Lignin, crude[1].....................	11.3	11.8	9.1	10.0
Nitrogen.............................	.67	.34	.26	.25
Cellulose, Cross and Bevan, ash-free.	49.4	59.8	58.1	56.7

[1] The lignin may be corrected for ash by subtracting 0.2 from the true lignin figures.

Analyses by Analytical and Physical Chemical Division, Northern Regional Research Laboratory, of hand-separated components, or parts, of cobs of the corn variety Illinois Hybrid 972 grown near Wyoming, Ill., in 1940.

Fuel or B.t.u. Value

Wiebe (5) reports B.t.u. values (oven-dry basis) of cobs ranging from 7,874 to 8,173 per pound and averaging 8,004 per pound. These values were determined in a Parr calorimeter and represent the "high" heats of combustion. The tests were conducted on 30 samples of cobs representing 21 corn varieties produced in 1940 and 1941 in various locations and on various types of soil. According to Wiebe, no systematic differences in results were observed between varieties or variations in the conditions under which the cobs were produced.

Results of calorimeter tests by the U. S. Agricultural Byproducts Laboratory, Ames, Iowa, are presented in table 7. These data show the B.t.u. heat value for cobs and other materials and their comparative worth based on coal of 13,000 B.t.u. at $10 per ton.

Table 7.-B.t.u. heat values for cobs and other materials and their comparative worth based on coal of 13,000 B.t.u. at $10 per ton

Material	B.t.u. per pound dry basis	Value per ton compared to coal of 13,000 B.t.u. per lb. at $10 per ton
		Dollars
Corncobs........................	7,980	6.14
Shelled corn....................	7,480	5.75
Cornstalks (flour)..............	7,175	5.51
Barley straw....................	7,700	5.91
Oat hulls.......................	7,445	5.73
Peanut shells...................	8,850	6.80
Pecan shells....................	8,950	6.89
Tobacco stems...................	6,100	4.70
Corncob carbon..................	13,400	10.30
Oat hull carbon.................	10,580	8.22
Peanut shell carbon.............	13,000	10.00
Pecan shell carbon..............	12,425	9.58
Peanut shell pitch[1]...........	13,900	10.70

[1] Derived from tar obtained by destructive distillation of shells.

Nutritive Value

According to Morrison (3), corncobs contain approximately 32 percent of fiber, with 0.4 percent of digestible protein and 46.2 percent of total digestible nutrients. Consequently this material can furnish but little more digestible nutrients than oat straw which Morrison reports as containing 36.1 percent of fiber with 0.9 percent digestible protein and 44.1 percent total digestible nutrients. Ground corncobs frequently are fed as a roughage to dairy cows but only in combination with grain or its byproducts.

Burroughs, Gerlaugh, and coworkers (6) at the Ohio Agricultural Experiment Station have studied the nutritive value of ground corncobs, and also corn-and-cob meal versus ground corn, in beef cattle rations. They conclude that "the nutritive value of corncobs in 13 digestion comparisons with 4 steers each averaged 51.6 pounds of total digestible nutrients in each 100 pounds of corncobs. This average figure suggests that cobs for cattle are 64 percent as valuable as the grain itself for energy or fattening purposes. In feedlot experiments, consisting of eight comparisons using a total of 192 cattle, the corncob replacement value of the corn grain averaged 62 percent. This value is regarded as tentative rather than as final with respect to all situations of cob utilization."

Monroe and Krauss (7) of the same station studied substituting ground ear corn for ground shelled corn in dairy rations. There was no marked difference in the liveweight gains on the two mixtures. Milk and butterfat production were a little higher on the ground shelled corn mixture than on the ground ear corn mixture. Monroe and Krauss conclude that there may be a slight financial advantage to be gained by feeding the ground ear corn.

Kannard and Chamberlin (8), also of Ohio, studied the case of corn-and-cob meal versus ground shelled corn in rations for chickens. They conclude that whenever the use of corn-and-cob meal results in better plumage conditions, less feather picking, and less cannibalism, it would often prove of far greater advantage than the disadvantages of slightly lower egg production and less body weight of the layers, as experienced in their experiments. The Wisconsin Agricultural Experiment Station (9) has carried on somewhat similar studies.

Heller[4/] in studying the nutritive value and vitamin content of corncob bran (glumes) states that this material has some nutritive value (a little more than oat hulls), probably as a carbohydrate source, and could be mixed with a protein concentrate to make a good feed. Vitamin A, measured biologically, was shown to be present in a negligible amount; carotene, tested chemically, was nil; the B-complex vitamins, measured biologically, were present; and vitamin D, measured biologically, was present in small amounts.

AVAILABILITY AND INDUSTRIAL PROCUREMENT

Proportionate Weight of Cobs in Ear Corn

The number of pounds of cobs per unit weight of ear corn varies with the variety, soil, climatic conditions, and the general moisture content of the ears at the time of shelling.

Table 8 gives the results of shelling experiments by the Northern Regional Research Laboratory on corn of moderately dry condition, representing several varieties grown in Illinois, Iowa, and Indiana. In these operations, the average weight of cobs per bushel of shelled corn ranged from 8.7 pounds for Illinois Hybrid 877 to 11.6 pounds for Sutton's white, an open-pollinated variety.

[4/] Personal communication from V. G. Heller, Department of Agricultural Chemical Research, Oklahoma Agricultural and Mechanical College, Stillwater.

Table 8.- Percentage and weight of cobs per bushel (56 pounds) of samples of shelled corn of the 1941 crop by varieties and source

Corn variety	Grown in -									Average		
	Illinois			Iowa			Indiana					
	No. of samples shelled	Yield of cobs per bu. (56 lb.) of shelled corn		No. of samples shelled	Yield of cobs per bu. (56 lb.) of shelled corn		No. of samples shelled	Yield of cobs per bu. (56 lb.) of shelled corn		No. of samples shelled	Yield of cobs per bu. (56 lb.) of shelled corn	
		Pounds	Percent		Pounds	Percent		Pounds	Percent		Pounds	Percent
Hybrids												
U.S. 13	8	10.0	15.1	3	10.3	15.5	6	10.0	15.1	17	10.0	15.2
U.S. 35	5	9.3	14.2	2	10.0	15.2	3	9.7	14.8	10	9.6	14.6
U.S. 44	3	10.1	15.3	5	9.9	15.0				8	10.0	15.1
Ill. 960	2	7.8	12.2	6	9.6	14.6				8	9.1	14.0
Ill. 200	3	10.1	15.3				3	10.9	16.3	6	10.5	15.8
Ill. 21	5	9.3	14.3							5	9.3	14.3
Ill. 784	5	9.4	14.4							5	9.4	14.4
Ill. 877	4	8.7	13.4							4	8.7	13.4
Iowa 13				6	9.3	14.3				6	9.3	14.3
Iowa 939				6	10.6	15.9				6	10.6	15.9
U.S. 63				3	10.1	15.3				3	10.1	15.3
Ind.608C							7	10.2	15.4	7	10.2	15.4
Ind. 610							3	9.7	14.7	3	9.7	14.7
Ind.613D							3	9.3	14.2	3	9.3	14.2
Ind. 844							9	9.6	14.6	9	9.6	14.6
Ind.416B							2	9.3	14.3	2	9.3	14.3
Open-pollinated												
Suttons white	1	11.6	17.1							1	11.6	17.1

These results are from samples, weighing about 15 pounds each, from farmers' fields of known seed source; ears were selected at random. All ears were well filled and practically free of husks which condition seldom occurs commercially. The shelling operations were performed by the Commodity Development Division, Northern Regional Research Laboratory, using a small motor-driven mechanical sheller. The corn was shelled when moderately dry, a condition corresponding to that usually prevailing in early spring commercial shellings.

In table 9 data are presented comparing cob yields of hybrid and open-pollinated varieties grown in two sections of Kansas. In the south central section of that State, where yields were comparatively low, cobs averaged 14.2 pounds per bushel of shelled corn for hybrid varieties as compared with 18.1 pounds per bushel for open-pollinated varieties. In the northeastern area, where corn yields were considerably higher because of more favorable conditions, the average weight of cobs per bushel for all corn is lower; however, hybrid varieties yielded lower weights of cobs, averaging 12.4 pounds per bushel as compared to open-pollinated varieties averaging 13.7 pounds per bushel.

The data presented in tables 8 and 9 are not strictly comparable with conditions encountered in the commercial shelling of corn, but they show a generally lower proportion of cobs in hybrid varieties.

Some variation in the weight of cobs per bushel of ear corn is due to those differences in soil and climatic conditions that affect corn growth and maturity. Particularly in years of low corn yields, when ears are not so well filled, there are usually more pounds of cobs per bushel of shelled corn than in years of good yields.

Seasonally, the proportionate weight of cobs in ear corn is greater in the fall when corn is first husked than in the following summer when the corn has reached a normal moisture content. In sections of the Corn Belt where a large proportion of the corn marketed is in the ear, 68 to 70 pounds of ear corn (depending on the time of year) is used as the equivalent of a bushel (56 pounds) of shelled corn. In sections in which the proportion of ear-corn marketings is relatively small, 70 to 80 pounds is used. Since 70 pounds of ear corn is usually the quantity considered equivalent to 1 bushel (56 pounds) of shelled corn, the cob equivalent of a bushel of shelled corn is, therefore, the difference between 70 and 56 pounds, or 14 pounds, and is the figure used hereafter in this report for calculating the quantity of cobs. It is probable that with higher percentages of hybrid corn varieties being grown each year the proportion of weight of cobs in ear corn has been declining slightly. It should not be construed, however, that elevators are necessarily profiting at the farmers' expense from the lower cob yield of hybrid varieties. In most instances competition among elevators forces adjustments in the per-bushel price offered for individual loads of corn to compensate for differences in expected shelling yields.

In table 10 are presented yield data for cobs and other products from shelling operations performed on a 50-bushel lot of ear corn of Illinois Hybrid 972.

Supply

The potential supply of cobs for industrial uses is dependent on the quantity of corn produced for grain. Obviously, the cobs from that portion of the crop produced for silage, grazing, forage, and hogging down cannot be considered as a practicable source of supply.

Corn is the most important crop in the United States both in acreage and in value. It is grown in every State of the Union, but more than half of the total is grown in the Central States (fig. 1). Iowa and Illinois are the leading corn-producing States.

Table 9.- Cob weights per bushel of samples of corn of specified hybrid and open-pollinated varieties, with their respective corn yields per acre, south-central and northeastern Kansas, average of 1939 and 1940 crops

Variety	Grown in south-central Kansas			Grown in northeastern Kansas		
	Yield of corn per acre	Yield of cobs per bushel (56 pounds) of shelled corn		Yield of corn per acre	Yield of cobs per bushel (56 pounds) of shelled corn	
	Bushels	Pounds	Percent	Bushels	Pounds	Percent
Hybrid varieties						
U. S. 35	27.9	14.2	20.2	77.8	11.4	16.9
U. S. 13	26.9	14.2	20.2	71.4	15.1	21.2
U. S. 44	24.4	14.1	20.1	71.8	11.6	17.2
Iowa 939	25.8	14.5	20.6	63.1	11.3	16.8
Average	26.2	14.2	20.3	71.0	12.4	18.0
Open-pollinated varieties						
Hays Golden	25.2	14.5	20.6	51.3	14.2	20.2
Reid Yellow dent				49.3	11.1	16.6
Freed	23.7	17.1	23.4			
Midland (a)	21.8	19.1	25.4	47.4	13.8	19.8
Pride of Saline	18.5	21.8	28.0	58.9	15.6	21.8
Average	22.3	18.1	24.4	51.7	13.7	19.6

Compiled from Kansas Agricultural Experiment Station Bulletins Nos. 288 (10) and 292 (11).

Table 10.-Cob and other yields resulting from shelling operations of a 50-bushel lot of Illinois Hybrid 972 corn of the 1940 crop

Product	Yields per bushel (56 lbs.) of shelled corn	
	Pounds	Percent
Shelled corn	56.0	83.70
Corn left on cobs	.5	.73
Cobs	10.0	14.93
Husks	.3	.44
Silks	.1	.17
Chaff loose from cobs	---	.03
Total	66.9	100.00

Shelling operations by Commodity Development Division, Northern Regional Research Laboratory, with small one-hole power-driven corn sheller.

The average United States corn acreage harvested for grain during the period 1930-39 approximated 82 million acres with production of corn for grain averaging almost 2 billion bushels (table 11). For the years 1944-46 with the same average harvested acreage, production of corn for grain was in the neighborhood of 2.8 billion bushels, representing a potential annual supply of cobs amounting to nearly 20 million tons.

Availability

Of the nearly 20-million-ton annual potential supply of cobs in the United States, only a small portion is economically available to industry. This portion, even though relatively small, is nevertheless great enough to support a large industry. The reason for the unavailability of some of the cobs is that they exist under conditions impracticable of collection or in such out-of-the-way locations or in such small quantities as to result in inordinately high collection costs. Conversely, the availability of cobs for industrial use is dependent upon their existence in substantial quantity in an accessible location and under conditions conducive to economical collection and transportation to processing sites.

The cobs resulting from large-scale shelling operations on the farm, from shelling operations at hybrid seed plants, and from shelling operations at mills and country elevators are the sources of supply most worthy of consideration.

Obviously, the cob accumulations at mills and country elevators are, as a general proposition, the most economical source of supply because they are present in such locations in greatest quantity and are in position for handling and shipping with the least effort and expense. Hybrid seed plants are a close second as an economical source. Experience shows that it is also practical and economical to obtain cobs from farm shelling operations. In many cases cobs have a negative value on the farm; they must be removed from the barnlot where the shelling takes place

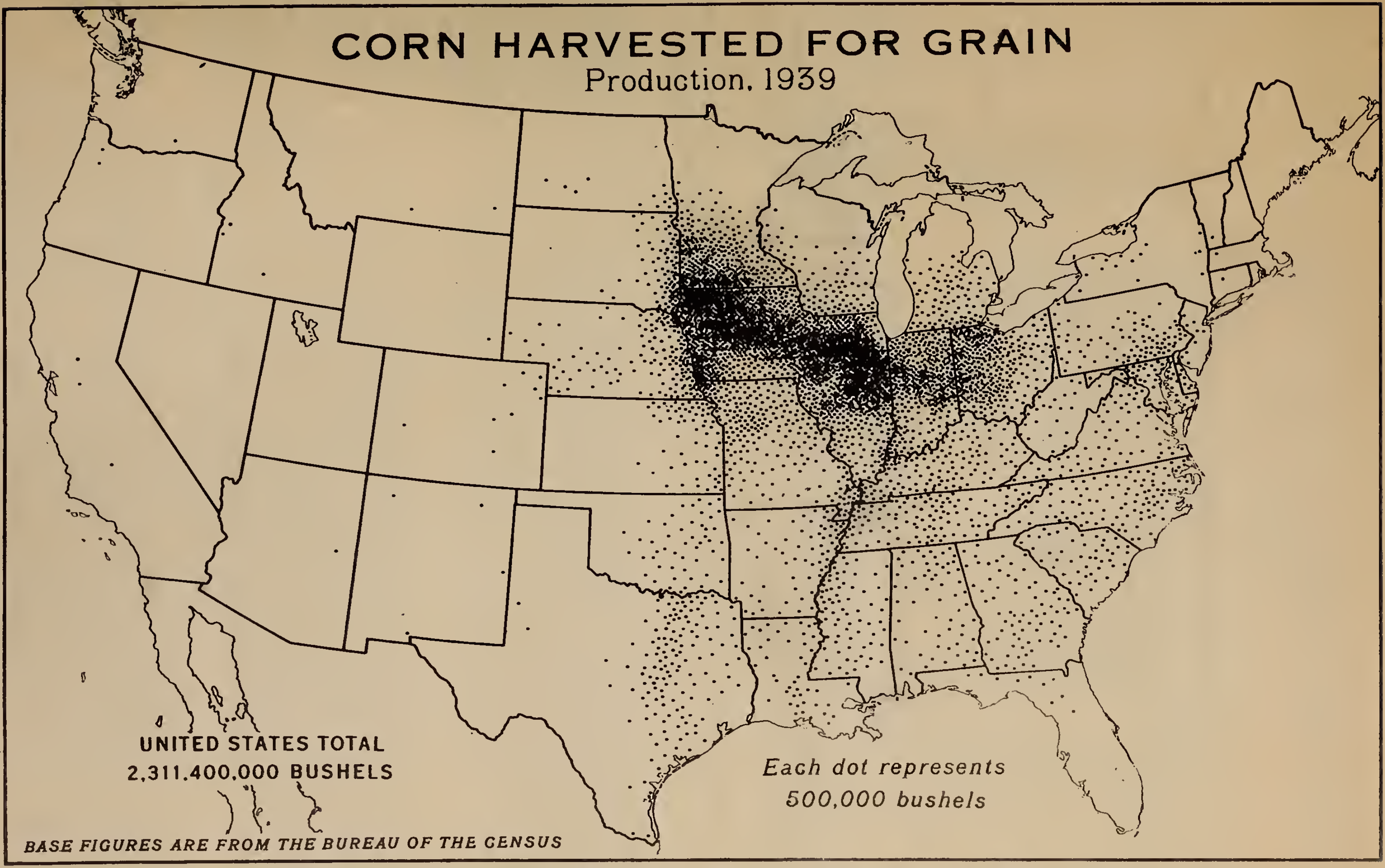

Figure 1.- In the Corn Belt, the area shown as nearly black on the map, corn production exceeds 3,000 bushels per square mile and in some counties rises to 5,000 bushels.

Table 11.-Potential supply of cobs[1] as represented by corn for grain production for selected states and U. S. total, crops 1944, 1945, 1946, and average for 1930-39

State and group	Average 1930-39		1944		1945		1946[2]	
	Grain	Cobs	Grain	Cobs	Grain	Cobs	Grain	Cobs
	1,000 bushels	1,000 tons	1,000 bushels	1,000 tons	1,000 bushels	1,000 tons	1,000 bushels	1,000 tons
Iowa	354,784	2,483	545,842	3,821	441,618	3,091	632,340	4,426
Ill.	292,620	2,048	388,575	2,720	360,654	2,525	495,330	3,467
Ind.	148,114	1,037	167,580	1,173	224,402	1,571	224,553	1,572
Nebr.	121,853	853	315,938	2,212	232,580	1,628	223,580	1,565
Ohio	124,348	870	131,518	921	166,398	1,165	166,845	1,168
Total for selected States	1,041,719	7,291	1,549,453	10,847	1,425,652	9,980	1,742,648	12,198
Total U.S.	1,984,836	13,894	2,881,303	20,169	2,593,752	18,156	2,989,887	20,929

[1] Calculated on the basis of a yield of 14 pounds of cobs per bushel of shelled corn.

[2] Preliminary source: Grain production figures are official statistics of U. S. Department of Agriculture.

because they are both a fire hazard and a nuisance. Commercial shellers have been glad to arrange for cob suppliers to provide trucks at farm shelling operations, so that the cobs may be loaded directly into them and hauled away. While neither the farmer nor the sheller receive money for the cobs, this service has proved valuable to them. Our surveys show that in Illinois, for example, there are several areas where 200,000 to 250,000 tons of cobs could be obtained within a radius of 50 miles from farm shelling operations.

The quantity of corncobs at country elevators in any particular area depends upon the amount of ear corn entering commercial channels. Under present conditions, cob accumulation at some elevators amounts to as much as 7,500 tons annually. Surveys show that a total of 100,000 tons of cobs collect annually at elevators within a radius of 80 miles of one locality in Illinois and 42,000 tons in an area 150 miles long and 40 miles wide in Indiana. The creation of a market for cobs might tend to bring about changes in the methods of marketing and handling which would result in increasing the supply of cobs at country elevators.

From 400 to 700 million bushels of corn are sold annually off U. S. farms where produced, the remainder or nearly four-fifths of the crop is retained on the farm where it furnishes the bulk of the concentrates fed to American livestock. The North Central States, known as the Corn Belt, accounts for over 80 percent of the corn marketed in the United States (fig. 2). Iowa and Illinois are the leading corn marketing States and account for more than three-fifths of this total. Minnesota, Nebraska, Indiana, Ohio, and Missouri follow in order in quantity of corn sold off farms.

Of all the corn sold off the farm, the proportion marketed as ear corn varies considerably with the locality. In Iowa, the southwest and south-central sections constitute the areas in which substantial amounts of ear corn are delivered to country elevators. No reliable information is at hand as to the exact amount of ear corn delivered to elevators in this area, but by including the contiguous southeast section of Nebraska, in which ear-corn marketing is also general, such marketings for the combined area would probably result in cob accumulations in excess of 30,000 tons annually at country elevators.

The principal ear-corn marketing section of Illinois embraces an area of 33 counties extending from east to west across the central part of the State. From surveys in this area it is estimated that 42 percent of the approximately 40 million bushels of corn annually sold there is marketed as ear corn, resulting in cob accumulations at elevators of around 118,000 tons annually (fig. 3).

Although ear-corn marketings in Indiana constitute a much larger proportion of total corn sold than in Illinois, the relatively smaller quantity of corn entering commercial channels results in comparatively small accumulations of cobs at elevators. The northwest and west-central sections of this State make up the area of largest cob concentrations at elevators. It is estimated that approximately 50 percent of the corn marketed in this area is sold as ear corn, resulting in, roughly, 42,000 tons of cobs (fig. 4).

The situation in Ohio is similar to that in Indiana. Most of the corn marketed is sold as ear corn but the total quantity sold is relatively small. Corn marketings and cob accumulations are predominant in the northwestern one-fourth of the State and the estimated annual accumulation of cobs at elevators in this area is placed at 30,000 to 40,000 tons.

Much snapped ear corn is marketed in western Tennessee along the Mississippi River. Approximately 7,000 tons of cobs are collected each year at Memphis, Tenn., due to such ear-corn marketings. About four-fifths of these receipts are handled by one company which at present is spending upwards of $2,000 annually for cob disposal.

Disposition of Cobs at Elevators or Commercial Shellers

When corn is marketed in the ear the problem of cob disposal is transferred from the farm to the country elevator where such corn is shelled before moving further in commercial channels. Most of the ear corn delivered to elevators is shelled immediately upon receipt, but if it has a high moisture content and the shelled grain cannot be quickly moved to a dryer, it is necessary to store it as ear corn. Because of relatively high transportation costs no ear corn is shipped to terminal markets.

Experience during World War II, when the tonnage of cobs used by industry expanded rapidly, has indicated that a large tonnage of cobs may be collected directly from farms. It is believed that in many instances farmers would gladly give a large portion of the cobs resulting from farm shelling operations free to anyone who would haul them away. Frequently arrangements are made by commercial shellers

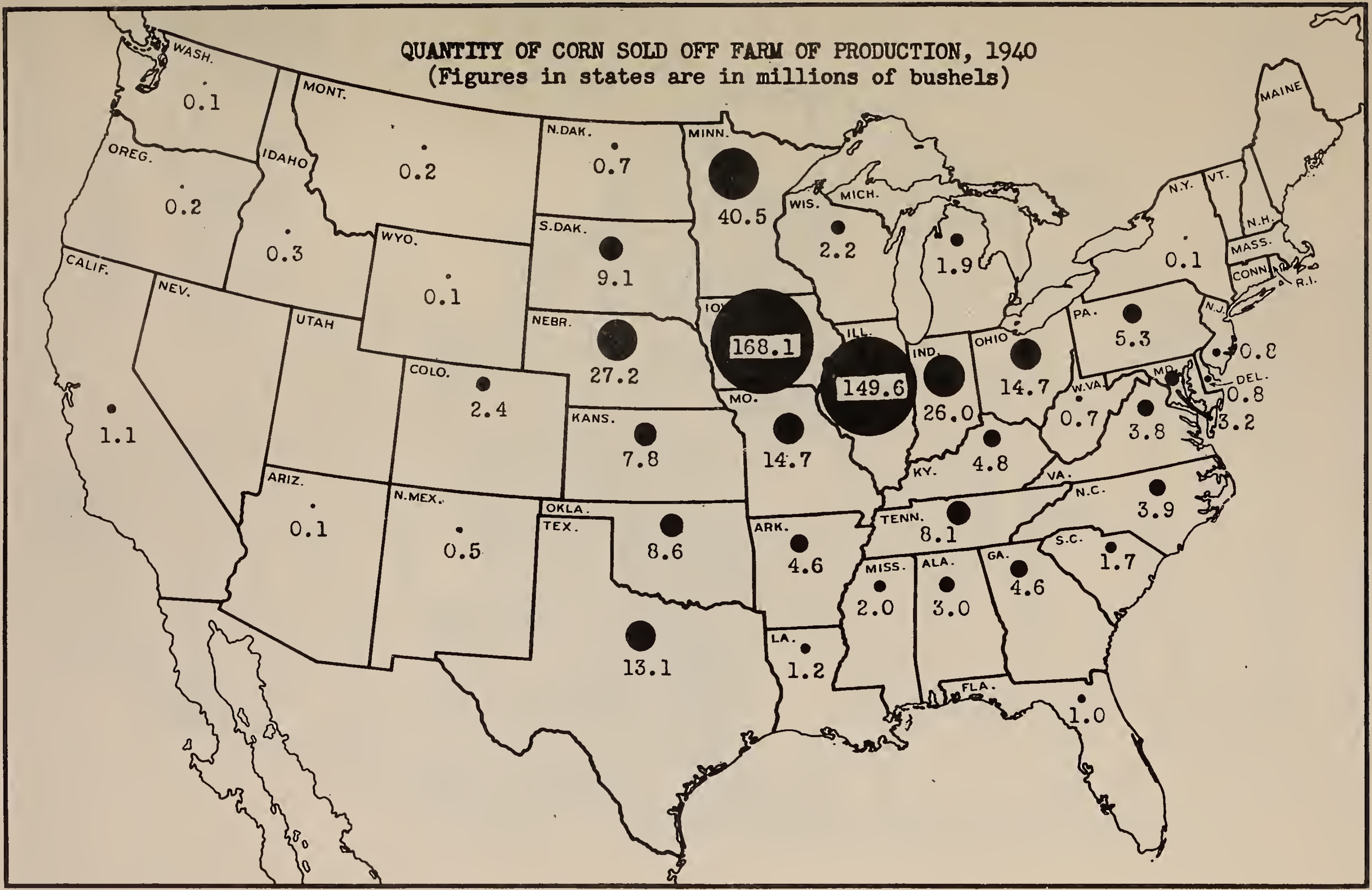

Figure 2.- A total of 538.5 million bushels of the 1940 corn crop sold off United States farms. Iowa, Illinois, Minnesota, Nebraska, Indiana, and Ohio accounted for 80 percent of such sales.

ILLINOIS, 1941

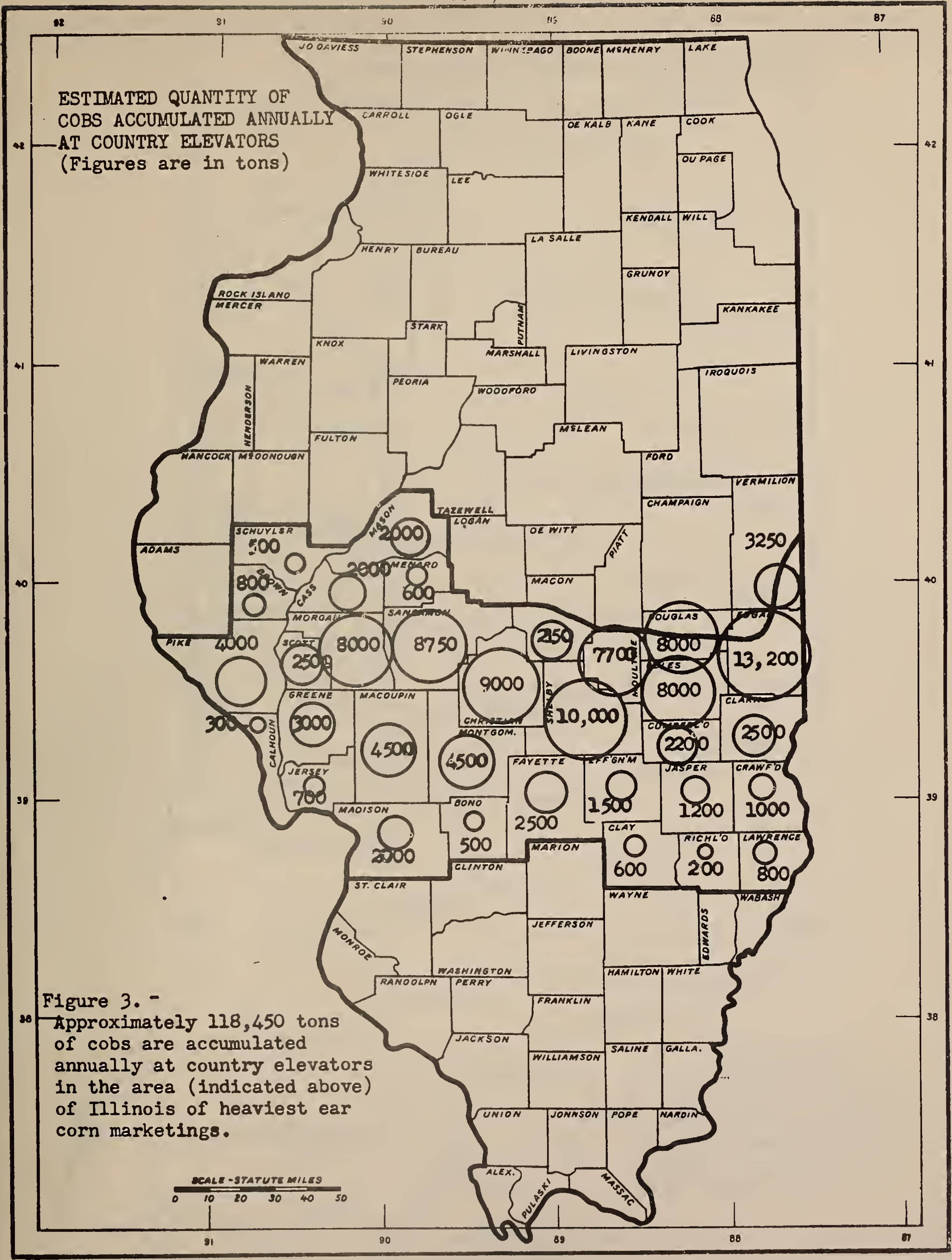

Figure 3. - Approximately 118,450 tons of cobs are accumulated annually at country elevators in the area (indicated above) of Illinois of heaviest ear corn marketings.

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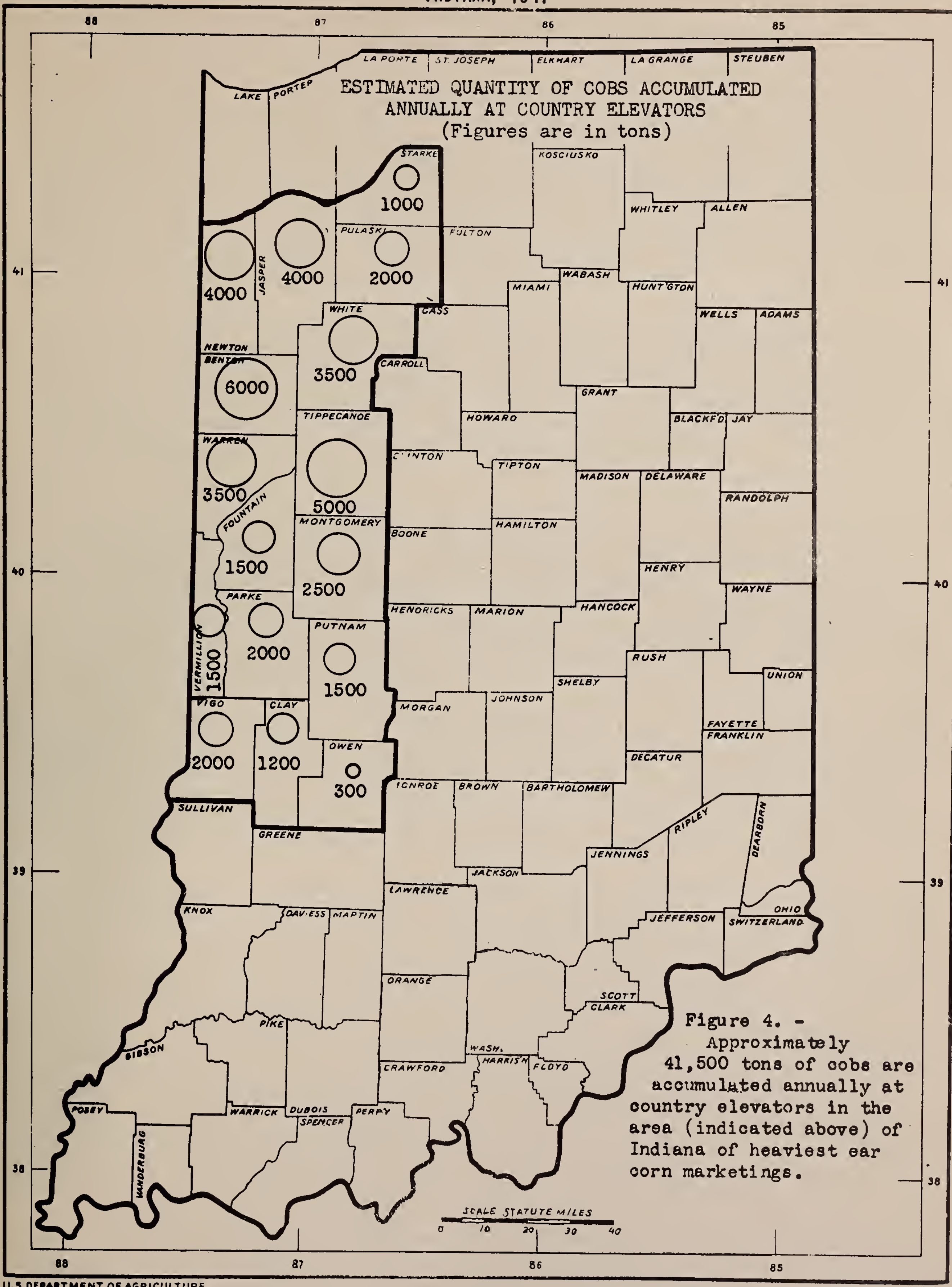
INDIANA, 1941



ESTIMATED QUANTITY OF COBS ACCUMULATED ANNUALLY AT COUNTRY ELEVATORS (Figures are in tons)

Figure 4. - Approximately 41,500 tons of cobs are accumulated annually at country elevators in the area (indicated above) of Indiana of heaviest ear corn marketings.

U.S. DEPARTMENT OF AGRICULTURE

to have the truckers who procure cobs for industrial use, put trailers adjacent to the shellers. In this way the cobs go into trucks in a clean condition directly from the corn shellers. This renders a service to the farmer in eliminating an unsightly fire hazard in the barnlot and saves him the expense of moving the cobs to some other site. Shellers, although usually not interested in receiving any pay for cobs, frequently cooperate with the farmer by arranging with truckers for removal service. In some areas elevators selling cobs to industry have paid a slight premium for corn delivered in the ear.

Most elevators receiving large quantities of ear corn are equipped with cob incinerators for burning their cobs. Occasionally an elevator makes use of cobs as fuel for heating or power purposes. In some instances elevators dispose of cobs by giving them to nearby residents for fuel. During and since the war, a considerable number of elevators and hybrid seed growers have disposed of their cobs to cob grinders or to plants producing furfural from them.

Cost

The highest price that industry can afford to pay for cobs depends on, first, the market value of the product or products derived therefrom and second, the price at which satisfactory substitute raw materials can be obtained. Because of this and the relatively high cost of collection and transportation of this material because of its bulkiness, farmers and other possessors of cobs must be willing to market them at a comparatively low price, otherwise industry will not be interested in utilizing them.

Various surveys have been made to obtain information on the over-all cost of cobs for processing use. The first such survey known to have been made was by LaForge (12) of the U. S. Department of Agriculture in 1920. He reported a delivered cost to processors of $4 or less per ton up to a distance of 30 miles. Since 1920, some of the factors affecting costs, especially those dealing with transportation, have changed greatly. Much of this information is probably obsolete.

A commercial firm, considering the utilization of corncobs for fermentation products, conducted a survey by mail during February 1928 to ascertain the cost of cobs at elevators within a radius of 75 miles of Terre Haute, Ind., and Peoria, Ill. Tentative prices asked for cobs by elevator operators in the Terre Haute area ranged from $1 to $5 per ton and averaged $1.68 per ton. The cost of transportation was computed at less than $2 per ton, depending on the distance hauled. The resulting estimated total cost was $3 to $3.50 per ton delivered to Terre Haute. The Peoria survey included elevators with and without shellers. The average tentative price asked by elevators with shellers was $2 per ton, and freight was calculated at $1.50, giving a delivered price of $3.50 per ton. Elevators without shellers asked an average price of $4 per ton, which, plus $1.50 freight charges, gave a delivered price of $5.50 per ton. Elevators without shellers were giving estimates of prices for cobs which they could obtain from farmers and not cobs resulting from their own shelling operations.

Surveys made by the Northern Regional Research Laboratory during 1941 were more detailed than the earlier ones cited in the preceding paragraphs. Elevator operators in Iowa, Illinois, Indiana, and Ohio were interviewed and first-hand knowledge of conditions was acquired. To arrive at specific cost figures, Decatur, Ill. was selected as a theoretical processing site on which to base the study because that city lies practically in the center of the ear-corn marketing area of Illinois, and all the 33 counties comprising it are within a 100-mile radius of that city. It is believed that cob prices and transportation charges, for all sections in the Corn Belt which have substantial quantities of cob accumulations at elevators, will approximate those determined for this section of Illinois.

In this 1941 survey, prices suggested by elevator operators for cobs loaded on trucks at the elevator ranged from 75 cents to $3 per ton, whereas the prices suggested for cobs loaded in railroad cars ranged from about 50 cents to $6 per ton. These suggested prices, no doubt, tended to be maximum in character and, obviously, in some instances were wishful thinking. The approximate average price for all elevators studied was $1.50 per ton loaded on trucks and $1.75 per ton loaded in boxcars at the elevators. These figures also included the cost of providing and maintaining facilities for short-term storage of cobs until they could be loaded.

Since a large percentage of corn is shelled at farm granaries, large quantities of cobs are available nearly everywhere throughout the Corn Belt. Farmers in many instances make no use of these cobs and either burn or otherwise dispose of them at some expense. In a 1946 survey it was found that collectors of cobs were obtaining large quantities from farmers who were glad to give their cobs away and in some instances even were willing to pay for their removal. Truckers hauling 3 to 4 tons per load collected these cobs and delivered them up to 15 or 20 miles to the shipping point or the processing plant for $2 to $2.50 per ton. Trucks of 10-ton capacity, in some instances, were used to haul cobs up to distances of 40 miles for $3.per ton. It appears, therefore, that the truckers, by cooperating with the operators of commercial portable shellers, could obtain cobs directly from the sheller and save the cost of loading and with the further advantage of getting cobs in prime condition. This survey indicated that cobs can be obtained from farms and delivered up to distances of 15 to 20 miles to the processing plant or central storage plant for $2.50 per ton.

During the period of 1943-46 large quantities of cobs were utilized for furfural production, grit blasting, feed, and other uses. Commercial cob collectors operating in Illinois, Indiana, Iowa, and Ohio shipped large quantities of cobs to processors, the largest of which were located at Memphis, Tenn., and Cedar Rapids, Iowa. Most of the cobs were collected from farms at the time of shelling. The shipping-point cost of these cobs, for deliveries up to 20 miles, varied from $2 to $3 per ton, depending on the locality. In the main corn-producing areas the delivered price was usually $2.50 per ton. In one instance where cobs were collected and stored and later delivered by truck to a point 80 miles away, the delivered price was $8 per ton.

Transportation costs

Because corncobs have a high degree of bulkiness in relation to weight and value, transportation charges will constitute a large part of their cost to industry. This can be alleviated somewhat by crushing, the cost of which, inclusive of loading into cars, is 50 cents to $1 per ton.

Specific weight tests conducted by the Northern Regional Research Laboratory on air-dry corncobs, crushed cobs, and cob meal are shown in table 12.

Table 12.-Approximate specific weights of whole cobs, crushed cobs, and cob meal

Material	Specific weight (pounds)	
	Per bushel	Per cubic foot
Cobs, whole...........	15	12
Cobs, crushed (approx. 1/2" pieces)..........	19	15 1/4
Cob meal ground in an attrition mill.......	30	25

Applying the specific weights given in table 12 to cubic capacities (2,700 to 3,700 cu. ft.) of boxcars, the maximum weight of whole cobs that could be loaded into a boxcar would range from 16 to 22 tons, crushed cobs from 20 to 28 tons, and cob meal from 32 to 44 tons.

During the war, crushed cobs were shipped in large quantities. Shippers reported that they were able to get from 20 to 37 tons in a boxcar, with an average of approximately 25 tons. The freight tariff for ground cobs is reported as being the same as that for grain, a basis of 20 tons as the minimum load. Whole cobs take a different rate.

Storage as a Factor in Cost of Cobs

Over 60 percent of total ear-corn marketings through country elevators occur during October, November, December, and January. The ear corn is usually shelled immediately upon delivery. Therefore, if processing plants using cobs are to operate on a year-round basis it is apparent that other sources of supply will have to be tapped or facilities will have to be provided to store large quantities sufficient for several months of operation. Probably most of the storage would take place at the processing plants. Because of the relative imperishability of cobs, elaborate storage facilities would not be necessary; cobs could be stored in open piles, and storage costs should be relatively low. One processor who has provided large-scale storage facilities reported that this storage plus the extra handling involved a cost of about $1 per ton. Based on this and other reports, it is believed that storage costs will range from 50 cents to $1 per ton. Corncobs would be available, however, from farm-shelled corn during most of the year and these could be used from the area adjoining the cob processing plant and thus lessen the tonnage of cobs that would need to be stored if only the cobs available at elevators were utilized.

FARM USES FOR COBS

The cobs resulting from farm shelling of corn are utilized or otherwise disposed of in various ways. Shelling is generally carried on in the barnlot and cobs are not only unsightly, but constitute a nuisance and a fire hazard. Industry is taking a small portion of these at present.

In Illinois, cobs are usually destroyed by burning immediately after shelling; however, in some cases a portion of them is stored and utilized for kindling fires. In Iowa, due to the relatively high price of coal, there is a considerable quantity of cobs used on the farm as fuel.

Cobs burn with a clean, hot flame, but the fire must be replenished frequently. When properly burned, the ash is small. In large part their use in the home is for the starting of fires or for cooking where heat is needed only for a short time.

In parts of Ohio and particularly in Indiana, cobs are put back on the soil, although agronomists do not rate them highly as fertilizer. In Indiana the spreading of cobs on sandy, less fertile soil is a common practice and seemingly results in increased yields of some crops. The cobs are also used to fill in swampy ground and low spots, thus assisting in drainage, because they decompose slowly. They are frequently used on alkali spots in the soil.

As noted, ground cobs in the form of corn-and-cob meal are used in certain states as a roughage supplement in the feeding of livestock, particularly beef cattle and dairy cows. A case is noted where distillery slops poured over ground cobs proved to be a good ration for cattle. The laxative properties of the slops were remedied by the presence of ground cobs. Certain states have passed laws against the addition of ground cobs to mixed feed.

Ground cobs form a suitable base for the poison baits for grasshoppers.

Cobs have also been recommended for use in smoking meat (1). For this purpose cobs which are not too dry are fired in a kettle in the smokehouse. In order to prevent the cobs from bursting into flame, they should be covered with earth to smother the flame after they have well started to burn.

There has been a recent revival of interest in the use of cobs for making sirup, which seems to have been an old custom. Sweeney (1) states that the sirup is made by boiling the cobs in water and adding glucose or cane sugar. The cobs probably contribute more flavoring properties than actual sweetening.

INDUSTRIAL USES

A great many industrial uses have been proposed for cobs and, although the subject has already received a considerable amount of attention, further studies are being carried on by the Northern Regional Research Laboratory. Prior to the war the industrial utilization of cobs was very small, which can be attributed more to economic factors than to a lack of knowledge necessary for preparing useful articles, chemicals, or chemical derivatives from them. Economic surveys made by the Northern Regional Research Laboratory in 1941 have assisted in the greatly expanded industrial use of cobs.

Since cobs, and most other agricultural residues, wood waste, sawdust, etc., are of similar chemical composition, chiefly cellulose, hemicelluloses and lignin, together with ash and small amounts of soluble materials, they are in a sense competitive with each other. The permanent use of cobs will, therefore, be based on their greater suitability to perform a particular service. Because of their physical characteristics, particularly because of the hard tough nature of their woody portion, ground cobs have found use in industry for certain special purposes.

Cob Grinding for Industrial Purposes

For most of their physical or chemical uses cobs must be broken or ground. During the past 7 years a great many small plants set up for grinding cobs have been in operation and it is possible to reach some conclusions from their experience.

Cobs are difficult to grind and because of their tough nature consume a great deal of power. Where grinding equipment is powered by electric motors the cost of electricity becomes an important item and this should be taken into account in locating grinding plants.

Because shelling operations are not 100-percent efficient, some grinders have salvaged a good many bushels of corn by passing the cobs through a sheller before grinding.

For coarse breaking on grinding of cobs, a variety of machines may be used. Rotary knife cutters do a good job. If whole cobs are passed through the fan of a blower system used for transporting cobs they will be broken into pieces of less than 2 inches up to 3 inches long. It is probable that cobs could be disintegrated even more finely by introducing them into an air blast and shooting them against a metal target. Equipment of this type is manufactured. This scheme would decrease wear and maintenance on the blower fan. The use of such systems would appear to make for low-cost preparation and the loading of cars for furfural manufacture or filling elevators, bins, or preparing outside storage piles.

For slightly finer grinding, to 1-, 1/2-, or 1/4-inch sizes, cob crushers of the burr type or sturdy hammer mills dressed with 1 1/2-inch or 1-inch screens have proved satisfactory. In general, the farm-type hammer mills are not sufficiently rugged to stand up in long service in cob grinding.

The available data concerning grinding rates is meager and the Northern Regional Research Laboratory is, therefore, undertaking a rather extensive study of the problem of grinding various agricultural residues, including cobs. Present data would indicate that a burr type mill or cob crusher will produce material, 75 percent of it passing a 1/2-inch mesh screen at the rate of 125 pounds per horsepower hour, and hammer mills dressed with 1-inch or 1/2-inch mesh screens will produce somewhat coarser material at the same rate.

Uniformity of feed and moisture content have an important bearing on grinding rates. For example, in a pilot-plant hammer mill dressed with a 5/8-inch screen, cobs containing 3 percent moisture were ground at the rate of 138 pounds per horsepower-hour while, under the same conditions, cobs containing 15 percent moisture were ground at just half that rate. For fine grinding, cobs should be relatively dry. For coarse grinding a higher moisture content is permissible. As noted, while the grinding rate increases with decreasing moisture content, very dry material introduces the possibility of smoldering in the finely ground product.

Hammer mills, if dressed with screens smaller than 1/2-inch mesh, are not suitable for fine grinding, since an appreciable quality of hard pellets are produced. Owing to its toughness and resiliency, the woody portion of the cob cannot be fractured readily in a hammer mill, hence the woody particles form into pellets which are recirculated and worn down to a size to drop through the screen. This results in particles unsuited for many uses, and power consumption is high compared with other types of grinding machines.

For the finer grinding of cob particles produced by the above methods two types of mills have been used, namely, the single- or double-disk attrition mill and the roller feed or flour mill equipped with corrugated rolls. These two types of mills produce particles of somewhat different physical characteristics.

In employing roller mills for cob crushing, all rolls are corrugated and are run sharp to sharp. It is obvious that a wide variety of operating conditions and character of product can be obtained depending on the number of pairs of rolls used, the type and spacing of their corrugations and other variable factors. No information is available on the production rates for the various types of cob products produced by these mills. The products produced by roller-mill grinding are very suitable for fur cleaning, burnishing and polishing of metals, fillers for soaps, floor sweeping compounds, etc. The physical form of these particles does not suit them so well for use as soft-grit blasting materials, since particles so produced are long in relation to their diameter. When used in an air blast such particles disintegrate rather rapidly.

A cutter mill, or preferably an attrition mill, is used for preparing soft grits for blasting, since it produces particles of about equal length and breadth. No satisfactory mill for producing flour (No. 80 or finer) from cobs has been found. This Laboratory has had experience with the ball mill and the double-disk attrition mill (24-inch). The ball mill operation is very slow and expensive. The attrition mill requires considerably more power to grind cobs than to grind wood shavings.

In producing soft grits for blasting, starting with screened crushed cobs 1- to 1/2-inch in size, it is possible to obtain a yield of 50 to 60 percent by attrition-mill grinding based on whole cobs, of grits passing a No. 12 and retained on a No. 35 screen[5]. Plant tests on a 36-inch double-disk attrition

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[5] Screen mesh sizes in terms of U. S. Standard.

mill indicate that at a feed rate of 14.2 pounds per horsepower-hour, this percentage of acceptable soft grits may be met.

In producing soft-grit blasting cob particles it is desirable to remove the beeswing and fine particles by a screen, reel, or an air blast before feeding the attrition mill. Provision must be made for a very uniform feed for the purpose of saving on power consumption. The ground material is then classified by collecting the material passing a No. 12 and retained on a No. 35 screen. This accepted material is then subjected to an air blast to remove beeswing and pith particles. The soft-grit material should not contain more than 13 percent moisture. Cobs obtained in the production of hybrid seed corn are best suited for the preparation of soft grits.

Two large-scale tests on a 36-inch double-disk attrition mill to produce corncob flour suitable for plastics (all passing a No. 100 screen) showed that with 1/4-inch cob particles produced by a hammer mill for feed, the over-all grinding rate was 10.7 pounds per horsepower-hour and the production rate 2.2 pounds per horsepower-hour, while with a feed of 1/8-inch particles the over-all grinding rate was 12.8 pounds per horsepower-hour. A pilot-plant test at this Laboratory on a 24-inch double-disk attrition mill using a fraction passing a 7/16-inch mesh screen and retained on a No. 12 screen had an over-all grinding rate of 12.4 pounds per horsepower-hour with a production rate of flour of 2.51 pounds per horsepower-hour. The 36-inch machine is the standard size (15) and a somewhat higher production per horsepower-hour is possible with this as compared to the 24-inch machine.

Fire and explosion hazards are present in grinding cobs. During grinding a considerable amount of heat is generated which may cause spontaneous combustion. When dry cobs are ground there is greater danger of this than with moist cobs. In coarse grinding there is little danger of fires with the coarse fractions, but any dust collected separately should either be blown away from the plant, bagged up immediately and inspected during early storage, or collected in metal bins preferably located outside the plant. With finer grinding the danger of fire is greater. Some grinders have given the cobs going to the grinders a light spray of water. At this Laboratory it was found that a small amount of steam blown into the pipe from the grinder to the cyclone will prevent smoldering. When the ground material collected in the cylcone is hot to the hand there is danger of smoldering. By sprinkling the cobs being fed to the grinder with water or introducing steam into the air stream of the collecting system, a point of addition will be found when the material feels cool to the touch. Such material will not smolder. If too much water or steam is added, condensation of moisture will take place in the cyclone, causing lodging and corrosion. The plant should be supplied with fire extinguishers. Finely ground material should not be stored in large lots but should be bagged immediately.

Magnetic separators should be connected with all grinding equipment to remove tramp iron. Sparks caused by foreign metal in grinders will start fires. Reels or screens used for separating the various fractions of ground cobs and cyclones require careful installation and maintenance so as not to produce dust in the plant. The housekeeping of a cob-grinding plant is most important and dust must not be allowed to accumulate on top of machines, beams, in corners, etc., so that dust explosions will not occur (13) (14).

Manufacturers of grinding and screening equipment and of elevators, cyclone dust collectors, and bagging machinery can be of assistance in recommending prop plant layout and the best types of machinery for performing the various grinding, separation, and packaging operations.

Stones picked up with the cobs and husks give trouble in grinding. Stones to some extent can be removed by passing the whole cobs over a coarse grid screen before grinding. Removing husks is troublesome. If the cobs are conveyed with air, the fan tends to remove many of the husks, which can be partially separated by air floatation or coarse screening. Husks tend to slow up all grinding operations. Coarsely ground cobs may be freed from husks and beeswing by fanning, and the beeswing recovered by screening. As will be noted later, some markets can be developed for husks.

No single method of grinding will produce economically a series of products of uniform and required specifications. When furnishing ground cobs for furfural manufacture, the whole grind, including the husks, can be sold as a unit. But when preparing cobs for either mechanical or physical uses, the grinder should plan to find a market for the entire grind, in order to obtain the most economical operation. As noted previously, power costs for grinding are high and the finer the product is ground in one operation the higher the costs. On the other hand, there is a certain portion of any grind that is oversize and a certain portion finer than desired. If a market can be found for the oversize and the fines, one grinding is all that will be required. If flour is desired, it should be produced by grinding the fine material obtained in producing coarser products. As an example, whole cobs could be crushed and aspirated to remove beeswing and husks; the coarse material could be screened between 0,5-inch and No. 8 screen; and the portion on the 0,5-inch screen should be returned to the crusher for further reduction and the portion on the No. 8 screen could be sold for chicken litter. The material passing the No. 8 screen could then be ground in an attrition mill to produce soft grits; particles too coarse to pass a No. 12 screen should be returned for further grinding; the particles passing a No. 12 screen but remaining after fanning are suitable for soft-grit blasting; the material obtained by fanning could be added to the beeswing; material passing the No. 35 screen could be run over a No. 60 screen and the particles passin the screen added in turn to beeswing or ground to flour; and the material retained on the No. 60 screen could be sold for burnishing or polishing.

Storage of Cobs

Due to the somewhat seasonal production of cobs, a plant operating throughout the year to grind cobs will find it necessary to stock-pile cobs for 4 to 5 months' operation. A study made by Dunning, Winter, and Dallas (16) of this Bureau shows that cobs may be stored in large piles in the open for this length of time without serious damage. The moisture content of such cobs, particularly in the outer layers, increases appreciably and it may be necessary to dry such wet cobs to keep grinding costs at a reasonable level.

Cobs have been stored under roof in a variety of structures. Frequently the sides of the structure so used are composed of lath or slats to provide free circulation of air in the cob pile. Whole cobs containing little dust should not heat up or sweat appreciably when stored, although a few cases of spontaneous combustion in cob piles have been reported. In one of these cases the cobs previously had been blown into the storage pile through a fan to break them. This caused an accumulation of fines and husk particles in certain parts of the pile. This tightly packed material underwent fermentation, and with no circulation of air to cool the material, it finally heated to the ignition temperature. Such a situation must be avoided and supervision of the piling operation, whether in open piles, elevators, or the like should be carried out to prevent accumulation of fine material to an extent that ventilation of the pile is hindered.

Cost of Grinding Plants

Grinding plants which have been installed or used consist of equipment ranging from a portable grinder and fan, to fairly elaborate layouts with several types of grinders, bucket elevators or air conveyors, reels or screens, cyclone dust collectors, and packaging machinery. It is impossible to estimate the cost of building a cob-grinding plant unless the tonnage of cobs to be ground and the type of products are known. The companies supplying grinding and other machinery can assist in working out the details of the layout and furnishing cost estimates of constructing and operating such plants. In general, plants grind from a few thousand to as much as 10,000 tons of cobs per year.

Too frequently plant investments have been made before markets for the products have been established. Successful operation will be found normally, to depend more on ability to merchandise the products and on good business management than on a good and efficient grinding operation. Cob grinding is a type of industry suited to the rural community but the markets for the products are not local; most extend beyond State boundaries and some may even be national in scope. The business is therefore not suited to and will not be successful in the hands of persons not capable of such kinds of merchandising and distribution. This statement does not always apply, however, to cob grinders serving chemical industries on a contract basis.

Industrial Markets Based on Physical Properties

Cob products are competitive in many uses with waste-wood products such as sawdust, shavings, etc. (17) and when such wood waste can find use without reprocessing, cob products will find such competition difficult or impossible. Markets for cob products should be developed, therefore, around those properties in which they prove superior to waste wood or other raw materials.

Corncob pipes.-Perhaps the oldest industrial use for cobs is the manufacture from them of tobacco pipes. Three companies in Missouri are engaged in this business and use approximately 15 million cobs per year, (18). A special type of stocky, woody, white cob with small pith center is required for pipe making. These are obtained from farmers in the Missouri River bottoms. The variety most suitable is a cross of the open-pollinated varieties, St. Charles, Boone County, and Indian Squaw. Select, properly cured cobs sold for as much as 40 to 60 cents per hundred several years ago. The waste from cob pipe manufacture is burned, supplying about half of the plant's fuel requirements.

Vinegar manufacture.-A small tonnage of whole cobs is shipped to the Pacific Coast each year for use in vinegar manufacture. The cobs are used as packing material in the vinegar tanks over which the wine trickles slowly to be converted

Chicken litter.-An increasing market is developing for coarsely ground cobs for use as chicken litter, especially in laying houses. When prepared for this purpose the cobs are coarsely ground and the fine materials screened out. Trials show that material passing a 0.5-inch and retained on a No. 8 screen are considered acceptable, although some poultrymen prefer particles up to 1 inch in length. For litter use cobs have the advantage of being bright in color, clean, and absorbant. Some grinders, after consultation with poultry experts, have added chemical ingredients to produce an improved litter. Often the litter is packed in attractively labelled paper bags and advertising literature is provided

Fur cleaning.-For about 20 years the woody portion of the cob, ground to pass a No. 12 and retained on a No. 20 screen and aspirated to remove dust and beeswing, has been sold in quantity for cleaning and dressing furs. Hard maple sawdust is also used for this purpose.

Soft-grit blasting of metals.-During World War II, the Nothern Laboratory, in cooperation with the Navy, developed a process for cleaning carbon, oil, and the products of corrosion from cylinders, pistons, and other parts of airplane engines by air-blasting the parts with a mixture of ground corncobs and rice hulls (19). These materials, after considering such factors as availability, first cost, total period of usefulness, and operating efficiency were the most satisfactory that had yet been found and were adopted as standard by the Bureau of Aeronautics of the Navy. The specifications call for corncobs ground to pass a No. 12 and retained on a No. 35 screen. The particles are fanned to remove pith and chaff. Not more than 13 percent moisture shall be present in the cob grits. The rice hulls are preferably ground coarsely through a hammer mill for use in the starting mixture. A mixture of 60 percent cob particles and 40 percent rice hulls, by weight, has been found to be most efficient. Rice hulls contain about 18 percent silica and are of too low density and too abrasive to be used alone. Also, they pulverize more rapidly in use than the cob grits and for that reason whole rice hulls should be added to the hopper of the blasting booth from time to time to keep the mixture in the proper proportions.

This method resulted in considerable savings in man-hours of labor as compared to the methods of cleaning with solvents and hand tools, making it possible to clean from 4 to 10 times as many parts in an 8-hour day. The process is almost fool-proof, since properly chosen soft grits do not change the close dimensions of the parts, and no masking, or hand tools are required. Careless and unskille operators using older means of scraping, turning on lathes, and sand blasting were responsible for the damage to many pistons and machine parts that sent them to the scrap heap.

By the soft-grit method, metal or other parts are first degreased and then cleaned in an air-blasting cabinet in which the soft grits may be collected in a hopper and recirculated. Eighty to 100 pounds per square inch air pressure is required for efficient operations. Since the soft grits are of lower density than sand, the suction on the cabinet for removing the dust should not be too high. In some installations it was found that the grits would not feed properly into the valve at the bottom of the hopper until the vacuum was reduced. In general, the pressure created by a fan system is satisfactory. The fine dust and dirt are blown to a dust collector. Dirt does not collect on the grits and they may be recirculated until entirely worn out. The cob particles, because of their tough character, last much longer than sand, and their overall cost is about that of the equivalent work done with sand. They can be used to clean many parts which sand blasting would damage and will do a safer and, in many cases, a just as efficient cleaning job. They will not clean mill scale from metals and are not adaptable where cutting is required. This method is not suitable for polishing metals, a matte surface resulting from its use.

Standard sand-blasting equipment has proved entirely satisfactory for handling soft grit materials and the pressure-blast type was preferred by the Navy to the induction-blast type. Certain manufacturers are now designing small cabinets especially suited for use of this method in garages and small shops.

Since the war, this Laboratory in cooperation with industry has developed a wide variety of civil uses for the soft-grit blasting method of cleaning. It is now used by many large companies rebuilding motors or by garages reconditioning spare parts. A prominent company stated that they have maintained their place in the spare-parts business only because of use of this method. At first this company anticipated an increased electric power cost but has stated that the extra power required for the air compressor is completely overshadowed by other intermittent uses for lights and motors. The method has found use in the rubber industry for cleaning molds for hard rubber and those used for recapping and molding new tires. The glass industry uses the method for cleaning molds. In the foundry the method is especially useful for cleaning aluminum molds and core boxes. Automobile lacquers and paint on metal surfaces are efficiently removed, glazed enamel is not harmed, and therefore enamelware is safely cleaned by this process. Rust, scale from hard waters, oil, grease, wax, and dirt are easily cleaned from steel, iron, brass, copper, and particularly objects made of the softer alloys.

Several cob-grinding operators are producing soft-grit blasting materials. One of the companies which supplied over 500 tons of corncob grits to the Navy states that civilian demand is increasing in a satisfactory manner. While considerable publicity has been given to this process of cleaning, it must be recognized that producers of grits will develop the market to the large proportions possible only by aggressive advertising and merchandising. This Laboratory has carried the development work to a point where a large-tonnage market may be visualized.

Burnishing of metals.-Corncob grits, because of their tough resilient character, are preferred by many companies for burnishing metals by the tumbling method. A very large tonnage of ground cobs was used during the war for burnishing cartridge cases and other products. A prominent arms manufacturer specified ground cobs passing a No. 12 and retained on a No. 50 screen. One of the large companies manufacturing both roller and ball bearings prefers cob particles passing No. 8 and retained on a No. 35 screen. Another grade passing a No. 16 and retained on a No. 35 screen finds a considerable market.

Polishing agents.-A finer grade of cob grits, passing a No. 35 and retained on a No. 60 screen is used for polishing. It has been reported that optical glass, band instruments, roller and ball bearings, metal pencils, brass and tin plate, aluminum ware, and similar articles are polished by this type of cob particles.

Absorbants for oil and sweeping compounds.-Cob grits are used for absorbing oil, the grade used for polishing being considered satisfactory for this purpose. Ground cobs are also used in sweeping compounds, competing for this purpose with sawdust. In most sweeping compounds, sand and oil are used together with sawdus or cob particles in varying proportions. The U. S. Treasury Department at one time used a compound of the following formula:

Sand..............	10 parts by weight
Fine sawdust......	3.5 parts by weight
Salt..............	1.5 parts by weight
Paraffin oil......	1 part by weight

Certain Government offices advise that a compound conforming to the following formula has been satisfactory in service:

Fine sand.........	35 percent by weight
Fine sawdust......	40 percent by weight
Paraffin oil......	15 percent by weight
Water (dye if coloring is desired).........	10 percent by weight

Corncob particles of suitable size may be substituted for the sawdust in such formulas.

Hand soap.-A use has been developed for cob grits, from white cobs, passing a No. 35 screen and free from dust as an abrasive agent in hand soaps.

Packing material.-Ground cob particles found a certain amount of use in packing metal parts for shipment during the war. These particles absorbed condensed moisture and minimized corrosion of the parts. A civilian use of this type for cob particles undoubtedly exists.

Uses with steel plate.-There has been some movement of whole and of ground cobs to steel mills within the past few years. It is understood that these are used for removing oil and that they also find use in separating steel or tinplate during the cooling period.

Asphalt shingles and roofing.-Cob particles have been used in the manufacture of asphalt shingles and roofing. The specifications of cob particles for such uses are not known but are probably similar to sizes used for burnishing.

Uses in manufacture of bricks and ceramics.-Light-weight bricks and ceramic objects often are manufactured by incorporating combustible particles in the clay. On firing, these organic particles burn up, leaving pores in the finished article. Cob particles have been used for this purpose. Particle sizes require vary with the ceramics manufacturer.

Miscellaneous uses as a filler.-Many attempts have been made to replace ground cork as a filler in linoleum floor covering, tile, shoe soles, and the like but, in general, the insolubility, resiliency, and other properties of cork have not permitted substitution in the higher grades of these products. The very tough nature of cob particles should suit them well to use as fillers in product subject to abrasion. There are undoubtedly countless uses for such cob particle in the manufacture of consumer goods. These uses can be uncovered by investigation, which must be conducted largely by industries that can use such material

Cob flour as a filler in plastics.-Wood flour has, from the beginning, been a standard filler in the manufacture of phenol-formaldehyde and certain other plastics. Wood flour comprises about 50 percent of the total weight of such plastic articles. The use of a filler in such plastics increases the strength properties and reduces cost. A number of ground natural products, such as nut shells, corncobs, sugarcane bagasse, flax shives, and hemp hurds have from time to time been investigated for this use, but with the exception of English walnut flour, such products have not been accepted by the industry. Investigations (20, 21) at this Laboratory have shown how corncob and rice hull flours, particularly, may be used for such purposes. Corncob flour for use in highly finished plastic should be fine enough to pass a No. 100 screen. For some uses material as coarse as No. 80 may serve.

While numerous inquiries for samples and prices on corncob flour have been made to cob grinders, little or no use of cob flour has thus far resulted, and it is doubtful if a market of any magnitude for cob flour will develop rapidly. There are several reasons for this. The plastics molding compounds used by custom molders are purchased mainly from the chemical manufacturers of the resins. Research by these companies has resulted in the formulation of a wide range of molding powders designed to produce plastics for many special purposes. A wide variety of molded articles may be manufactured from what is known as "general purpose" molding powders, which generally contain about 50 percent wood flour. The use of corncob flour would appear to involve some modifications in resin formulation to produce articles as satisfactory as those using wood flour. Molding compounds containing much less than 45 percent resin require more care in molding than general purpose compounds. Corncob flour is not as bright or light in color as the better grades of wood flour. Also corncob flour costs about as much to produce as wood flour. At present the largest manufacturers of such molding powders are located on the eastern or western seaboards with suppliers of wood flour located much nearer their plants than points in the Middle West. Thus, transportation costs to manufacturers are higher at present on corncob flour except in the Corn Belt. The large custom molder or the manufacturer who is in a position to compound molding powders and to mold in the Middle West may find an advantage in the use of cob flour.

For feed.-The beeswing is frequently sold as a bran-like filler for feed, but several states have legal restrictions on such usage. During the feed shortage in the early 1940's many carloads of cobs ground to pass a 1/8-inch mesh screen were sold for use in feeds. Material having this specification makes an excellent absorbent for molasses used in producing high-carbohydrate feeds. When mixed with hot molasses the cob particles absorb their own weight of molasses and produce a free-flowing product.

Mulch and litter.-Coarsely ground cobs are frequently used as a mulching materia Reports indicate that ground cobs are suitable for hog bedding.

Mushroom culture.-Partially rotted cobs have been used successfully by commercial mushroom growers.

Oil-well drilling.-Cobs ground to pass a 1/4-inch mesh screen have been used in Colorado to restore circulation of muds in the drilling of oil wells.

Uses for husks.-The following uses for corn husks have been reported: As feed, as bedding material, and as a packing material for pottery. For the latter use it is said to be preferred to wood excelsior. Husks could be used by the strawboard industry, but in general their production by any grinder is probably too small to warrant interest by the paper mill. Furthermore, higher prices can probably be obtained in the other fields of uses mentioned.

Industrial Uses Based on Chemical Properties

The manufacture of chemical products from cobs is generally not suited to small rural industry. Capital investment in buildings and manufacturing equipment is relatively high, running from a quarter of a million to several millions of dollars. Merchandising must be of a national character. Highly trained engineers and chemists are essential and research is necessary to insure survival of the business.

Furfural.-At present, furfural is the most important chemical made from cobs. The basis for this process was laid by research of this Bureau (22) almost 30 years ago. In 1922 a company (23) making food and feed products from oats undertook commercial manufacture of furfural from their waste oat hulls. The basic patents on the process have now expired but the original producer is still the sole producer of furfural in this country. Present production capacity of two large plants located at Cedar Rapids, Iowa, and Memphis (24), Tenn., exceeds 20,000 tons annually. Corncobs now represent the chief agricultural raw material, being used to the extent of about 150,000 tons per year. Oat hulls are still used at Cedar Rapids and rice hulls and cottonseed-hull bran are also used at the Memphis plant.

Furfural, ($C_4H_3O{=}CHO$) is a liquid aldehyde with an odor somewhat like oil of bitter almonds. It is nearly colorless when first prepared, but darkens on exposure to light and air, The most up-to-date information on plant facilities, operations, and costs of producing furfural is given in a report by the Secretary of Agriculture to Congress in 1946 (24). A flow sheet of the process used at the Memphis plant has also been published (25). The operations in the manufacture of furfural are essentially as follows:

The raw materials, particularly corncobs, are ground to pass a 1-inch screen and are sucked from railway cars or trucks to storage warehouses, and from there to concrete silos provided with devices for uniformly feeding the residues over continuous weighing devices into 14-foot rotary, spherical digesters lined with carbon blocks. Five-percent sulfuric acid solution is added, then digesters are closed and brought to about 70 pounds pressure by the introduction of live steam. Under these conditions of acid and heat the hemicelluloses are converted to furfural which can be distilled out of the digester with the steam. The vapors of furfural and steam from the digester are scrubbed and then, when cooled, the condensed furfural and water separate into two layers. By a special method of distillation, refined technical furfural and a small amount of byproducts are obtained. The residue consisting of lignin and degraded cellulose is dried and burned to produce power, or is sold as a fertilizer filler. The yield of furfural is in the neighborhood of 60 percent of that theoretically possible. Owing to the use of corrosive acids, equipment and maintenance costs are high. Furfural is sold in drums and in tank-car lots. Present prices are 9.5 cents per pound in tank-car lots.

The production of furfural expanded gradually until, by 1940, it was about 6 million pounds per year. While attention was given to the use of furfural for the manufacture of chemicals, its industrial usage, in the main, developed as a solvent in the purification of wood rosin, in the purification of petroleum lubricating oils, and in purifying vegetable oils. Also, a considerable amount was used to produce phenolic plastics and a smaller amount to make chemical derivatives. The production of synthetic rubber from petroleum during World War II developed a large-scale new use for furfural as a selective solvent. In certain processes it is necessary to purify the important rubber intermediate, butadiene, from other petroleum hydrocarbons, such as the butanes. Furfural proved to be excellent for this purification step. The greatly increased requirements for furfural, due to this use, resulted in the Government building a plant at Memphis, Tenn. This plant, which had a production capacity of 15,000 tons per year, has now been sold to private industry and its capacity is being increased.

A variety of chemical products made from furfural are being manufactured by several companies. The more important of these products are furfuryl alcohol, which finds a growing market in the manufacture of low-pressure plastics; tetrahydrofurfuryl alcohol, an excellent solvent and useful in producing plasticizers; and furan and tetrahydrofuran, solvents and intermediates for the manufacture of a variety of chemicals, the most important of which is dichlorobutane. This last-named chemical is now used to produce adiponitrile, one of the important intermediates used in the manufacture of nylon. The company manufacturing nylon (26) has recently announced the building of a plant to produce adiponitrile from furfural. This nylon process alone will use furfural in the equivalent of 100,000 tons of corncobs per year.

Processes are also available for producing other chemicals such as furoic acid, vinyl furan, hydrofuramide, methyl furan, tetrahydromethylfuran, etc. The Northern Regional Research Laboratory is carrying on extensive work on the industrial uses of furfural and has developed processes for producing 1,3-pentadiene (27); 1,4-pentadiene (27); 1,4-pentanediol (29); 1,5-pentanediol (28); dihydropyrane (25); ∂-hydroxyvaleraldehyde (28); acetopropyl alcohol (29); and ∂-valerolactone (30).

Cass (26), in his discussion of the furfural-adiponitrile process, states: "This field of chemistry (furan) will show as many outstanding results in the next decade as did the field of benzene chemistry or the field of lower aliphatic chemicals when they were first intensively evaluated."

Fermentable sugars, solvents and liquid fuels.-Everyone is familiar with the contribution of agriculture in supplying starch, sugar, and grain for the production of alcohol for rubber, explosives, and other uses during the war. Penicillin excepted, persons are generally less familiar with the fact that a wide variety of important chemicals are produced by the fermentation of sugars by various yeasts, molds, and bacteria.

In all of these fermentation processes, sugars derived only from agricultural products, are the chief raw material. The search for low-cost sugars has therefore been a challenge to the scientist for years. Low-cost fermentable sugars means low-cost motor fuels, solvents, medicinals, and many other products.

For instance, chemists have known for more than 100 years that starch or cellulose may be converted to the sugar, glucose, by treatment with acids. Glucose is fermentable to alcohol by yeast. Numerous patents describe processes for converting wood or sawdust, containing about 60 percent cellulose, to fermentable sugars and to a lignin residue, so far useful only as fuel. Blackstrap molasses, a byproduct of the sugar industry, for many years has proved the lowest-cost source of sugar for alcohol production, selling in tank-car lots at New York before the war at an average price of 7 cents a gallon and in 1932 as low as 3.6 cents a gallon.

Until recently, the most economical process for converting wood to sugar was that developed by Scholler in Germany. Although this process was supported by state subsidy, it proved to be of the greatest importance to the Axis powers in World War II. Three Scholler process plants operated in Germany, two in Italy, one in Switzerland, and one in Korea. The sugar produced was, for the most part, used for cattle feed in two ways: as direct carbohydrate source and for the production of high-protein fodder yeast. At Springfield, Ore., a plant using a modified Scholler process, which was developed at the Forest Products Laboratory of the U. S. Department of Agriculture, Madison, Wis., has been constructed. There are prospects of utilizing the enormous quantities of wood waste now available in lumbering areas. This process will prove economic if profitable uses for the lignin can be developed.

Cost estimates for producing sugars from agricultural residues indicated that it was questionable if any cellulose saccharification process which depended wholly upon fermentable sugars as its sole revenue could compete with blackstrap molasses. From the business angle, however, it was conceivable that a profitable process might be developed if, together with the production of glucose, there could be produced at the same time another chemical for which there was an established market with a good profit margin.

Fortunately from this standpoint, agricultural residues contain, in addition to cellulose, other complex carbohydrates known as pentosans in which the residues are much richer than is wood. On treatment with acids, pentosans are converted first into a sugar, xylose, which is not fermentable by yeast, but which on further treatment with acid is converted to furfural. In the present process for manufacturing furfural the cellulose of the corncobs, oat hulls, etc. is decomposed and appears in the residue, together with the lignin, which is sold as fuel or as a fertilizer filler.

Lathrop and Dunning of the Northern Regional Research Laboratory believed that if the right conditions could be found it should be possible to produce both glucose and xylose or furfural from agricultural residues, such as corncobs. In developing such a process it was necessary to obtain the glucose and xylose or furfural in high yields and in relatively concentrated solutions. The result of their research (31) was so successful that a semi-commercial processing plant has been built in Peoria to determine the feasibility of commercial production.

Funds for erecting the plant and carrying on the extended semi-works investigatior were supplied by Congress through the Bureau of Mines under Public Law 290 under the Act of April 5, 1944, for the production of synthetic liquid fuels from coal, oil shales, agricultural and forestry products, and other substances. This semi-works study is being carried out under the Bureau's Synthetic Liquid Fuels Projec The semi-works operations will provide a basis for computing costs and determinin the commercial feasibility of the commercial production of fermentable sugar solutions and furfural from corncobs. The fermentation of the sugar solutions to solvents or to liquid fuels is a part of the investigation, but this will be carried on in the fermentation pilot plant of the Northern Regional Research Laboratory. The testing of the motor fuels produced will be conducted by the motor fuel testing group of the Laboratory.

The semi-works plant for saccharifying agricultural residues has a production capacity of 2,000 pounds of glucose in 10-percent solution, 1,600 pounds of xylos in 15-percent solution, 200 pounds of furfural, and 1,000 pounds of lignin from 6,600 pounds of corncobs in an 8-hour day. In commercial practice the plant would operate on a 24-hour schedule. Since the process is continuous, each step follows the other automatically. In processing corncobs, for instance, the cob is never seen from the time it leaves the storage bin for ground cobs until the saccharified liquid material, ready for fermentation or other treatment, emerges.

It will be noted that four products are produced during the saccharification operation. One of these is the sugar glucose, also known as corn sugar. This can be fermented to alcohol by yeast or to butanol, acetone and alcohol by the microorganism, Clostridium butylicum. Both of these are well-known industrial fermentation processes. Prior to the development of this saccharification proces no one had been able to ferment the sugar xylose to butanol, acetone, and alcohol, except in the presence of large amounts of glucose. Xylose is not fermented to alcohol by yeasts. This Laboratory has now developed a process (32) for the fermentation of xylose to butanol, acetone, and alcohol in yields similar to those obtained industrially from glucose or blackstrap molasses. This process is now being studied in the fermentation pilot plant. Large-scale fermentations of both the xylose and the glucose solutions in the fermentation pilot plant will demonstrate the commercial feasibility of producing alcohol, butanol, and acetone. These chemical compounds are known to have value as motor fuels and, in addition, have a multitude of uses in the chemical and other industries.

It is also possible to separate xylose in good yield in the form of the pure crystalline sugar. Corn sugar can also be obtained in crystalline form from the glucose solution. Laboratory studies to be followed by pilot-plant operations are under way to determine the process steps and costs of producing these pure sugars.

Using corncobs as an example of an agricultural residue suitable for this saccharification process, a brief description of the process is as follows:

> The cobs are crushed to pass a 1 1/4-inch screen and are fed into a long cylindrical chamber which is jacketed and heated by steam. Sulfuric acid of about 5 percent concentration is heated to boiling and is pumped into the other end of this chamber. The ground cob particles are carried through the chamber by means of a screw device, then are carried out of the chamber through a mechanism which drains off the acid. The acid-treating solution emerges from the bottom of the cylinder at the end where the cobs are fed, is collected, and pumped to a storage tank. The pentosan sugars have been extracted during the operation to the extent of about 95 percent by the acid solution and are present in the solution to an extent of about 15 percent concentration. The residue from which the pentosan sugars have been extracted is passed through a dewatering press, such as is used for manufacturing dried distillers' grains, and the acid extracted from this residue is returned to the acid-storage tank feeding the pentosan extractor.
>
> The dewatered residue which still contains some acid is now dried to less than 1 percent moisture in a rotary drier. The dried material is ground to pass a No. 40 screen. This material is then fed into a molasses mixer and sprayed with about one-third of its weight of 85-percent sulfuric acid, cold water being pumped through the jacket of the mixer in order to prevent the temperature from rising. The material emerges from the mixer as a dry powder and is run directly into a specially-designed screw press from which it emerges as a plastic mass. This mass is treated with about 10 parts of cold water in a high-speed mixer, and the slurry formed is pumped under about 30-pounds pressure directly through a steam-heated coil. The mixture coming from this coil is passed over a continuous filter to remove the insoluble lignin. The clear solution contains about 10 percent of glucose sugar.

The 15-percent xylose solution or 10-percent glucose solution, before fermentation, must be neutralized with lime to remove the sulfuric acid. Neutralization of either of these solutions can be carried on continuously. When the calcium sulfate that is formed is filtered from these solutions they are ready for fermentation. The glucose solution may be fermented by yeast to alcohol and the xylose solution fermented by bacteria of the species Clostridium butylicum to butanol, acetone, and alcohol. If, instead of fermenting the xylose solution it is desired to produce furfural from it, the acid from the pentosan extractor does not need to be neutralized, but by a special digestion process, depending principally on heating, it is possible to convert the pentosans to furfural in high yields. Furfural is obtained as a distillate with water from the condensation of the steam from the digester. This furfural may be purified in the usual manner and is ready for conversion by known methods to liquid fuels, solvents, or industrial chemicals.

The accurate operating cost and plant-scale design data which are expected to come from this semi-commercial plant investigational work may be several years in materializing because that much time may elapse before the manufacturing process can be fully proved. These factors will have a decided bearing on the probable use of alcohol and other fuels as a supplement to gasoline. If experimental laboratory results are borne out in the semi-works operations, from 90 to 95 gallons of liquid motor fuels will be obtained from each ton of residues, about half in the form of ethyl alcohol. The ultimate aim is not to supplant gasoline as a motor fuel but to test the possibilities of making these fuels cheap enough for use as blending agents. If expectations are realized, however, a greatly expanding market for agricultural residues such as corncobs, flax shives, peanut shells, and the hulls of rice and cottonseed will exist. Because the economics of the process depend upon capitalizing the value of the pentosan constituents, agricultural residues, being richer than wood in such components, are a preferred raw material.

Corncob lignin - uses.-Nelson (33,34,35) has shown that lignin extracted from corncobs by alkaline cooking followed by precipitation with acid and washing, is useful in removing iron from potable waters. The lignin obtained from the saccharification process described above is probably satisfactory for such purposes, and experiments to determine this are planned. The alkaline extraction process of obtaining lignin from corncobs is too costly to compete with lignin obtained from waste soda of sulfate cooking liquor in the pulp and paper industry. On the other hand, lignin from saccharification of wood or residues would probably represent its cheapest source.

A great deal of attention has been paid to the use of lignin in the production of plastics, but with very poor success. In general, the lignin seems to serve mainly as a filler, and while lignin plastics have good water resistance, they are somewhat brittle and generally lacking in strength.

It is generally believed that there is a great similarity between lignin and the humic acid in the soil. From various reports where saccharification lignins, from one process or another, have been added to the soil beneficial results have been obtained. There is room for much exact experimental work to establish the relation between lignin and humic acid. A number of soil experts and agronomists have become interested in this use of lignin as a soil amendment and are cooperating with this Laboratory in an effort to clear up the question.

Destructive distillation of corncobs.-It is possible to produce charcoal, gas, and a number of chemicals by the destructive distillation of wood, agricultural residues, or lignin. From a commercial standpoint the process of destructive distillation has been of diminishing importance during the past 25 years. Originally the process was a basic industry, and hardwoods served as the principal raw material; but the production of methanol, acetic acid, and acetone by synthetic processes with the substitution of the coke-iron process for former charcoal iron, and increasingly higher wood costs have restricted the wood-distillation industry to a few plants. This Bureau has given attention to the possibility of a commercial process for the destructive distillation of corncobs and other residues and the results are reported by Jacobs (36) and by McElhinney and Becker (37). There seems to be no industrial possibilities along these lines.

Heat and light on the farm from corncob fermentation gases.-It has been known for some time that materials containing sugars, starches, cellulose, or hemicelluloses will ferment with certain types of bacteria in the absence of air to produce a mixture of gases composed of approximately 50 percent carbon dioxide, 25 percent methane, and 25 percent hydrogen. This gas mixture will burn. This process is in use by some industries to dispose of certain types of industrial wastes. About 10 years ago the Bureau built a small pilot plant at Ames, Iowa, to explore the possibilities of using such a process to produce heat and light on the farm from agricultural residues. Jacobs (38) reports this study. A ton of corncobs may be assumed to yield 10,000 cubic feet of gas having a heating value of about 500 B.t.u. per cubic foot. About 50 pounds of cobs would have to be charged into the gas machine per day to produce the 200 cubic feet of gas assumed to be the average farm house consumption requirement. At that time the cost of equipment was estimated at $750 per small installation. The fermentation process is rather slow and the fermenting mass requires rather uniform temperature (39) control. Nitrogen-containing compounds must be added to feed the bacteria and the production of acids in the fermenting liquid must be prevented. It was concluded that the technical operating controls made the process impractical from the standpoint of farm use.

Producer and synthesis gas from corncobs.-Producer gas from wood and charcoal has been and is still used outside the United States in many countries where abundant suitable raw materials are available, as in Sweden, France, Germany, and many tropical countries. In some instances agricultural waste products are used in stationary generators. An annotated bibliography (40) gives a fairly complete picture of the widespread use of this type of fuel.

During World War II a brief investigation was made at this Laboratory and it was found that the gas produced from corncobs equalled that from wood in quality (41). More recently full-scale gas producer experimental work at the Wellman Engineering Company, Cleveland, Ohio (42) using cottonseed hulls and various other agricultural residues, substantiates previous results that the gas produced is suitable for internal combustion engines. The economy of the process hinges on the cost of residues. Up to the present in this country there have been no installations of producer-gas plants using agricultural residues.

The Fischer-Tropsch process for making liquid fuels from carbon monoxide and hydrogen, extensively used in Germany during the late war, is not being introduced into this country. A gas of the proper composition for making liquid fuels by this process may be made from agricultural residues, such as corncobs. However, cost calculations show that the cost of cobs must be approximately $1 per ton to compete with low-grade coal.

Pulp, paper and board manufacture.-Questions and suggestions frequently come to this Laboratory regarding the suitability of cobs to produce rayon and cellulose paper pulps. Cobs are not a preferred material for such uses. The alpha-cellulose content is low and the impurities which must be removed from the pulp are higher than from the soft and most of the hard woods. In addition, the ultimate length of the cellulose fibers of the cob is very short. Pulping tests at the Laboratory have shown that this fiber length characteristic would cause large fiber losses in washing and screening and that over-all production costs would prevent such pulps from competing with pulp wood or fibrous residues such as the cereal straws or sugarcane bagasse.

Some efforts have also been directed to the production of building materials such as wall tile, accoustical tile, and the like from ground corncobs. In producing such articles it is necessary to use resin as a binding material, generally of the thermosetting type. Ten percent or more of such resin binder is required to produce articles of sufficient strength. It appears possible to produce products which have merit, but the question of costs and ability to compete with presently manufactured board products made from wood pulp or sugarcane bagasse should receive careful attention by those interested in carrying on such developments. Sawdust and shavings available at many wood-working plants at practically no cost seem equally suitable for the manufacture of similar resin-bonded tile.

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LITERATURE CITED

(1) Sweeney, O. R. 1924. Commercial utilization of corncobs. Iowa State Col. Engin. Expt. Sta. Bul. 73.

(2) Wiley, H. W. 1898. Composition of maize (Indian corn) including the grain, meal, stalks, pith, fodder, and cobs. U. S. Dept. Agr. Bur. of Chem. Bul. 50.

(3) Morrison, F. B. 1939. Feeds and feeding, 20th Edition. 1050 pp., illus. Ithaca, N.Y.

(4) Winton, A. L. and K. B. 1932. Structure and composition of foods. Vol. 1. 710 pp. illus. New York.

(5) Wiebe, R. March 1942. Unpublished report of Agricultural Motor Fuels Division, Northern Regional Research Laboratory, U. S. Dept. Agr.

(6) Burroughs, Wise, Gerlach, Paul, Shalk, A. F., Selver, E. A., and Kunkle, L. E. 1945. The nutritive value of corncobs in beef cattle rations. Jour. Animal Sci. 4 (4): 373-386.

(7) Monroe, C. F., and Krauss, W. E. 1946. Simple vs. complex grain mixtures in dairy rations. III. The effect of substituting ground ear corn for ground shelled corn in the simple grain mixture. Ohio Agr. Expt. Sta. Bimonthly Bul. 31 (240); 65-73.

(8) Kennard, D. C., and Chamberlain, V. D. 1946. Corn-and-cob meal versus ground shelled corn in rations for chickens. Ohio Agr. Expt. Sta. Bimonthly Bul. 31 (241): 104-113.

(9) Wisconsin Agricultural Experiment Station. 1944. Bul. 466, Part II, p. 54. (61st Ann. Rpt. of the Director for year ending June 30, 1944.)

(10) Clapp, A. L. et al., Kansas corn test, 1939. 1940. Kans. Agr. Expt. Sta. Bul. 288

(11) Juganheimer, R. W., et al. Kansas corn test, 1940. 1941. Kans. Agr. Expt. Sta. Bul. 292.

(12) LaForge, F. B. 1920. A practical study of corncob utilization. Chem. Age (New York) 28:332-6.

(13) Edwards, P. W., and Leinbach, L. R. 1935. Explosibility of agricultural and other dusts, as indicated by maximum pressure and rates of pressure rise. U. S. Dept. Agr. Tech. Bul. 490.

(14) Price, D. J., and Brown, H. H. 1922. Dust explosions. Nat'l Fire Protection Ass'n. Boston. 2nd Ed. 246 pp., illus.

(15) Ginaven, M. F. 1946. Wood flour manufacturing. Chemurgic Digest 5 (7): 129-31-32.

(16) Winter, P., Dunning, J. W., and Dallas, D. The availability and storage of corncobs and other agricultural residues for saccharification process. Synthetic Liquid Fuels Project, Bur. Agr. and Indus. Chem., U. S. Dept. Agr. Agr. Engin. 29:11-13, Jan. 1948.

(17) United States Department of Agriculture, Forest Products Laboratory. 1934. Outlets for waste wood. Cir. R64. (Mimeographed).

(18) Anonymous. 1941. Missouri meerschaum. Newsweek 17 (20):52.

(19) Lathrop, E. C., and Aronovsky, S. I. 1945. Soft-grit blasting of metals. Compressed Air Mag. 50:268-272.

(20) Clark. T. F., Williamson, R. V., and Lathrop, E. C. 1945. Agricultural residues in plastics. Part I. Agricultural residue flours. Modern Plastics 23:158-160, 214, 216, 218.

(21) Williamson, R. V., Clark, T. F., and Naffziger, T. R. 1946. Agricultural residues in plastics. Part II. Plasticizers and inorganic extenders in 25-percent phenolics. Modern Plastics 23:177-180,220,222.

(22) Monroe, K. P. 1921. Preparation and technical uses of furfural. Indus. and Engin. Chem. 13:133.

(23) Peters, F. N. 1937. Furfural as an outlet for cellulosic waste materials. Indus. and Engin. Chem. 15:269.

(24) Letter from the Secretary of Agriculture. 1946. Federally-owned plants and facilities. Senate Document 167 (Furfural, The Q-O Chemical Co., Plancor 1233). p. 32.

(25) Anonymous. 1945. Production of furfural. Chem. and Metall. Engin. 52 (7):132-35.

(26) Cass, O. W. 1947. Farm wastes to be used in manufacture of nylon. Chemurgic Digest 6 (6):97 and 99.

(27) Schniepp, L. E., and Geller, H. H. 1945. The preparation of 1,3- and 1,4-pentadienes from furfural. Jour. Amer. Chem. Soc. 67:54-56.

(28) Schniepp, L. E., and Geller, H. H. 1946. Preparation of dihydropyran, δ-hydroxyvaleraldehyde, and 1,5-pentanediol from tetrahydrofurfural alcohol. Jour. Amer. Chem. Soc. 68:1646.

(29) Schniepp, L. E., Geller, H. H., and Van Korff, R. J. 1947. The preparation of acetylpropyl alcohol, and 1,4-pentanediol from methyl furan. Jour. Amer. Chem. Soc. 69:672.

(30) Schniepp, L. E., and Geller, H. H. 1947. Dehydrogenation of 1,5-pentanediol Jour. Amer. Chem. Soc. 69:1545.

(31) Dunning, J. W., and Lathrop, E. C. 1945. The saccharification of agricultural residues. A continuous process. Indus. and Engin. Chem. 37:24.

(32) Langlykke, A. F., Van Lanen, J. M., and Fraser, D. R. 1947. The productior of butyl alcohol from xylose saccharification liquors. (Presented at meeting of Amer. Chem. Soc., Atlantic City, April 1947.) Indus. and Engin. Chem. (In Press).

(33) Nelson, G. C., Levine, Max, and Lynch, D. F. J. 1939. Removal of iron by lignin in water treatment. Paper Trade Jour. 108 (9):117-120.

(34) Nelson, G. H. and Aronovsky, S. I. 1941. The use of lignin for removal of iron from water. Paper Trade Jour. 43 (19);31-37.

(35) Nelson, G. H., Levine, Max, and Lynch, D. F. J. Removal of metallic elements from water. U. S. Patent 2,269,315 (Issued Jan. 6, 1942).

(36) Jacobs, P. B. 1940. Destructive distillation of agricultural wastes. Indus. and Engin. Chem. 32:214.

(37) McElhinney, T. R., and Becker, B. M. 1939. Destructive distillation of corncobs. Indus. and Engin. Chem. 30:697-701.

(38) Jacobs, P. B. 1934. Heat and light on the farm. The Architectural Record 75 (4):358-368.

(39) Nelson, G. H., Straka, R. P., and Levine, Max. 1939. Effect of temperature of digestion, chemical composition and size of particles on production of fuel gas from farm wastes. Jour. Agr. Res. 58(4):273-288.

(40) Nowakowska, J., and Wiebe, R. 1945. Bibliography on construction, design, economics, performance, and theory of portable and small stationary gas producers. Northern Regional Research Laboratory, Bur. Agr. and Indus. Chem., U. S. Dept. Agr. Mimeographed Cir. AIC-103.

(41) Porter, J. C., and Wiebe, R. Gassification of agricultural residues. Northern Regional Research Laboratory, Bur. Agr. and Indus. Chem., U. S. Dept. Agr. In preparation.

(42) Lustig, L. 1947. New gas producer for Diesel fuel engines. Diesel Progres: 13 (5):42-43.

ADDITIONAL REFERENCES

Manglesdorf, P. C. and Reeves, R. G. 1939. The origin of Indian corn and its relatives. Texas Agr. Expt. Sta. Bul. 574, 315 pp. illus.

Robbins, Wilfred W. 1924. The botany of crop plants. 2nd Ed. 674 pp. illus. Philadelphia.

Rommel, George M. 1928. Farm products in industry. New York.

Weatherwax, Paul. 1923. The story of the maize plant. Chicago